Phase 1 UFLS Review: Queensland

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 Queensland, 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.

DISCLAIMER

This document or the information in it may be subsequently updated or amended. This document does not constitute legal or business advice, and should not be relied on as a substitute for obtaining detailed advice about the National Electricity Law, National Electricity Rules or any other applicable laws, procedures or policies. AEMO has made every effort to ensure the quality of the information in this document but cannot guarantee its accuracy or completeness.

Accordingly, to the maximum extent permitted by law, AEMO and its officers, employees and consultants involved in the preparation of this document:

- make no representation or warranty, express or implied, as to the currency, accuracy, reliability, or completeness of the information in this document; and
- are not liable (whether by reason of negligence or otherwise) for any statements or representations in this document, or any omissions from it, or for any use or reliance on the information in it.

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 Queensland 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 Queensland, and the likely impact on the effectiveness of under frequency load shedding, AEMO is sharing these early findings so that investigation on next steps can proceed in parallel with AEMO's analysis in Phase 2 of the UFLS review.

Key findings

- The annual minimum total net load in the Queensland UFLS scheme decreased from 2,400 MW in 2018-19 to 2,351 MW in 2019-20. This minimum is projected to continue to decrease as DPV installations increase, with total UFLS load potentially reaching 1,715 MW by June 2023.
- AEMO assessed the total net load in the Queensland UFLS scheme as a percentage of the total underlying load in Queensland.
  - 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 will 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.
  - For this analysis, AEMO has used total underlying load (calculated as operational demand + DPV generation[1]) 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).

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] 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

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. If this analysis indicates that the amount of response required could be less than 60% of underlying load in some periods, it may be acceptable for NSPs to target a value lower than 60% in some periods.

- This analysis indicates that net load in the Queensland UFLS scheme is often below 60% of underlying load during periods with high DPV generation:
  - For the 2019-20 year, in periods with no DPV generating, net UFLS load was close to 60% of underlying load (in the range of 56-62%) the majority of the time. However, in periods with high levels of DPV operating (>900 MW), net UFLS load was below 60% of underlying load in all periods, and in some periods was as low as 41% of underlying load.
  - By 2022-23, with continuing growth in DPV based on growth factors taken from the 2021 ESOO Net Zero 2050 scenario, net UFLS load is projected to fall as low as 29% of underlying load in some periods.
- A number of UFLS circuits have been observed in reverse flows. 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. This is detrimental to UFLS performance.
  - Some UFLS circuits exhibit reverse flows a significant proportion of the time, in both day and night periods. These appear to be related to larger distribution connected generating units.
  - Many additional UFLS circuits are also showing periods of reverse flows which appear to be largely related to the generation of DPV. At this stage, reverse flows at these feeders are generally observed less than 2% of the time. This is expected to grow over time as the level of DPV installed grows.

Next steps

This analysis demonstrates that net load in the Queensland UFLS scheme is decreasing due to continuing growth in DPV. It has also identified a number of UFLS circuits that appear to have reverse flows.

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 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 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 the Jurisdictional System Security Coordinator (JSSC), 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:

- **Removing UFLS circuits in frequent reverse flows**. Specific locations where this issue has been identified are listed in Section 3.5, and AEMO is seeking NSP advice on other possible locations that may be similarly affected. AEMO is seeking advice on the technical and economic feasibility of the following possible remediation approaches, and any others suggested by NSPs:
  - Removing the affected UFLS circuits from the UFLS scheme
  - Dynamically arming UFLS relays, so that they automatically disarm when the circuit is in reverse flows.
  - Introduce arrangements such that loads on the UFLS circuit are tripped by UFLS relays, but the generation remains connected.
  - Or any combination of the above approaches, on a case-by-case basis.
- **Introducing active monitoring of total net UFLS load**. Consider the feasibility of establishing a real-time SCADA feed for total net Queensland UFLS load (and possibly net UFLS load in each sub-region), so this can be monitored by AEMO and NSPs, and used to inform real-time intervention if required.
- **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.
  - Removing UFLS 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 suggestions 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. 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.

Contents

Tables

Figures

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 Key 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 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 Queensland. 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[2]. 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[3].

[2] 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

[3] 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, JSSC and Market Customer 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 Queensland (Energy Queensland and Powerlink) during 2020 to construct the necessary datasets for this analysis, as outlined in the sections below.

Half-hourly load data

In Queensland, most UFLS relays are located at the 11 and 22kV level in the network. These UFLS relays trip "feeders" of the distribution network. AEMO aggregated the feeder level half-hourly load measurements provided by Energy Queensland, to estimate the total amount of load in the UFLS at each frequency trip setting, in each half hour, for 2018-19 and 2019-20.

Data cleaning was applied prior to the aggregation of the half hourly load data. The feeder data files provided contained outliers and null values due to reasons such as outages, load switching, maintenance events and/or metering issues. To deal with such discrepancies, the following approach was used prior to aggregation:

- All values more than 5 standard deviations from the mean were made null, assuming this is due to a measurement failure.
- Consecutive null values < 24 hours (48 time intervals) were interpolated, assuming this is due to a data outage.
- Consecutive null values > 24 hours (48 time intervals) were set to zero, assuming this is due to a load outage or maintenance.

Large industrial customers

Powerlink supplied half-hourly load data for transmission connected customers included in the UFLS schedule at the 132kV, 110kV and 66kV level. Customer feeders were grouped by their frequency and time delay settings and mapped to their corresponding load data. This load data was cleaned using the approach outlined above, aggregated, and summed to determine the total amount of load at each trip setting, in each historical half hour for financial years 18/19 to 19/20.

Installed capacity of DPV

The installed capacity of DPV on each feeder was supplied by Energy Queensland for distribution connected installs in the size range 0-30 MW. The total install capacity provided by Energy Queensland was compared to DPV installed capacity data from the Clean Energy Regulator (CER). The NSP total installed capacity for QLD in June 2018 was found to be approximately 260 MW lower than the total installed capacity obtained from the CER for June 2018 and approximately 640 MW lower for June 2020.

For this analysis, the installed capacity of DPV data provided by Energy Queensland was scaled according to regional DPV generation data from AEMOs forecasting system ASEFS2. The installed capacity per feeder in 2018-19 and 2019-20 was summed by UFLS trip setting, then converted to a percentage of the total installed capacity for QLD.

Note that no DPV data was provided by Powerlink as no load customers have installed capacities except those that are registered generators.

Future projections

This assessment includes some simple forward projections of UFLS load from 2020-21 to 2022-23, assuming continued growth in DPV installations and underlying demand (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 assumed to continue at the rate projected by the 2021 ESOO Net Zero 2050 scenario and applied to each equally to each sub-region (growth of 18% on 2019-20 for 2020-21, 42% on 2019-20 for 2021-22 and 62% on 2019-20 for 2022-23).

The DPV end of financial year installed capacities supplied by Energy Queensland were scaled up to the 2021 ESOO actual installed capacities which are closely aligned with the data from the CER. The generation on each trip setting was scaled up in each year, based on the Net Zero 2050 scenario growth rates.

The future underlying demand growth rates were assumed to continue at the rate projected by the 2021 ESOO Net Zero 2050 scenario (growth of 0.23% on 2019-20 for 2020-21, 1.13% on 2019-20 for 2021-22 and 1.67% on 2019-20 for 2022-23).

The underlying load for industrial customers was assumed to be equal the operational load provided by Powerlink (PL) as they were stated to have no DPV installed:

PL Underlying load 2019-20 = PL Net load 2019-20

The residential and commercial underlying load in the 2019-20 financial year in each half hour was estimated from the operational load provided by Energy Queensland (EQ) as:

EQ Underlying load 2019-20 = EQ Net load 2019-20 + PV generation 2019-20

The half-hourly underlying load for industrial customers in future years was assumed to remain identical to the 2019-20 reference year. The half hourly underlying load for residential and commercial customers in future years was projected from the 2019-20 reference year by applying growth rates that achieved the same growth as the Net Zero 2050 scenario for underlying load in Queensland. 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 trip setting was then calculated as:

Net load 2022-23 = PL Underlying load 2019-20 + EQ Underlying load 2022-23 - PV generation 2022-23

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

Sub-region allocation of data

To extend this analysis the data supplied by the NSPs was separated into Queensland sub-regions (North, Central and South). This allows exploration of the performance of UFLS during sub-regional separation events. Sub-regions were constructed based on postcodes, with boundaries aligned to Powerlink cut sets of the transmission network.

To allocate Energy Queensland's data into sub-regions, feeder IDs were grouped to substation, then postcode, then sub-region. This mapping is approximate as some feeders service various postcodes and may traverse sub-region boundaries.

To allocate Powerlink's data into sub-regions, customer loads were grouped to substation, then sub-region using transmission level single line diagrams (SLDs).

3. Findings

3.1 Net load in UFLS

Figure 1 shows a duration curve of the total net (measured) load in the Queensland UFLS scheme in financial years 2018-19 and 2019-20. Indicative future projections are also shown. In the 2019-20 financial year, total Queensland UFLS load reached a maximum of 5,173 MW and a minimum of 2,351 MW, and most of the time is within the range 2,700 – 4,000 MW.

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

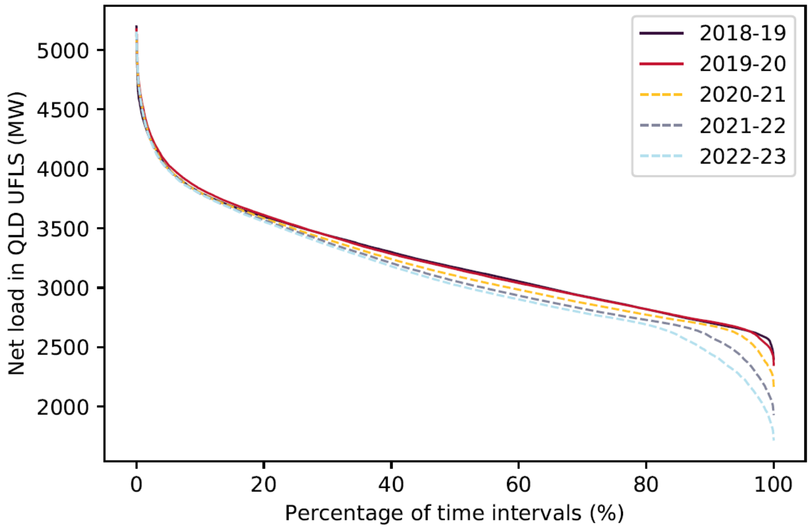


Figure 2 shows the same duration curve, focusing on the year-by-year changes in the lowest load periods. This shows that net UFLS load in Queensland is projected to decline in the lowest load periods as DPV installations continue to grow.

Figure 2 Queensland UFLS load duration curves in historical and future years (80% - 100%)

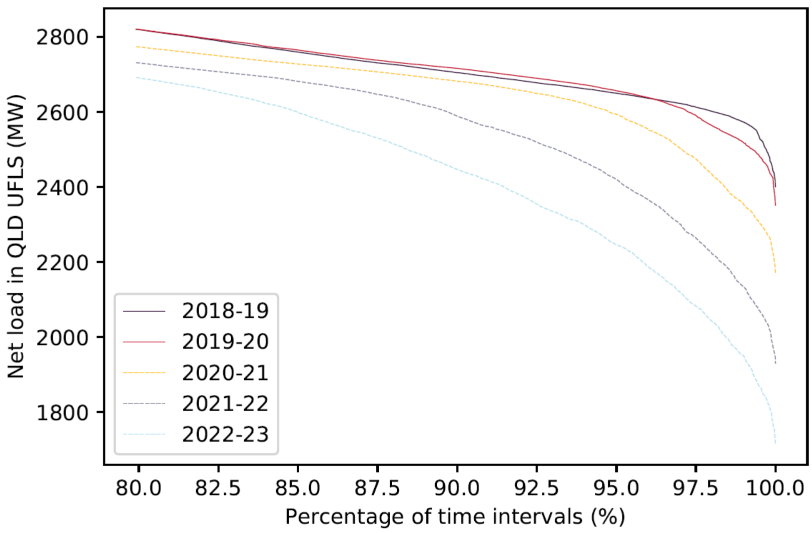


Figure 3 shows the minimum net UFLS load measured in the Queensland UFLS scheme over the past two years. The minimum periods occurred on 2 September 2018 in 2018-19 financial year, and 3 May 2020 in the 2019-20 financial year. The minimum UFLS load has decreased somewhat from 2,400 MW in 2018-19 to 2,351 MW in 2019-20.

If DPV growth continues at the projected rates, and underlying load growth in the lowest demand periods is as projected in the 2021 ESOO Net Zero scenario, this decline in net UFLS load is projected to continue, with minimum UFLS load in Queensland potentially reaching as low as 2,166 MW in the 2020-21 financial year, and 1,715 MW in the 2022-23 financial year.

Figure 3 Queensland minimum net UFLS load in historical and future years

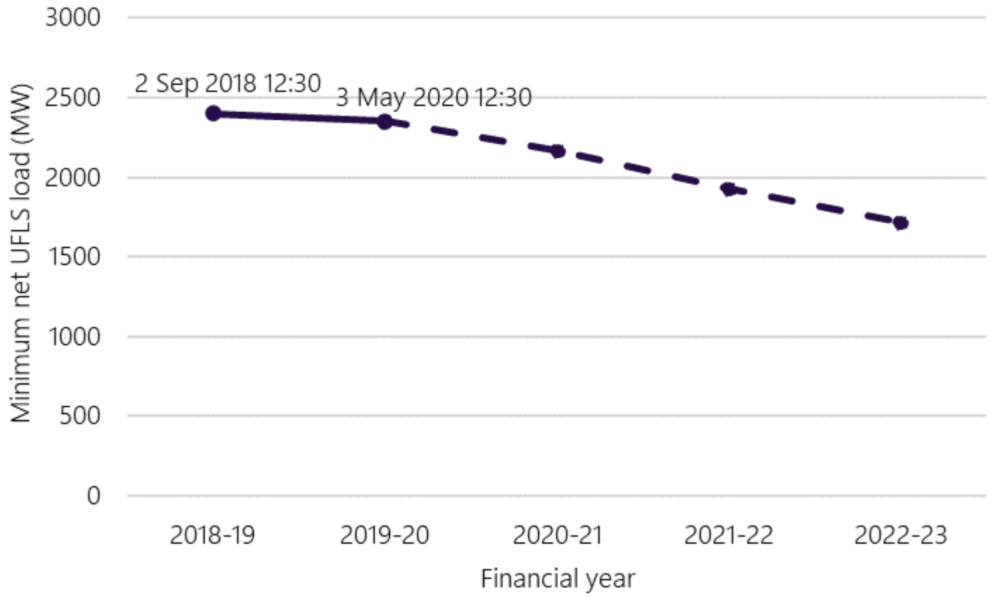
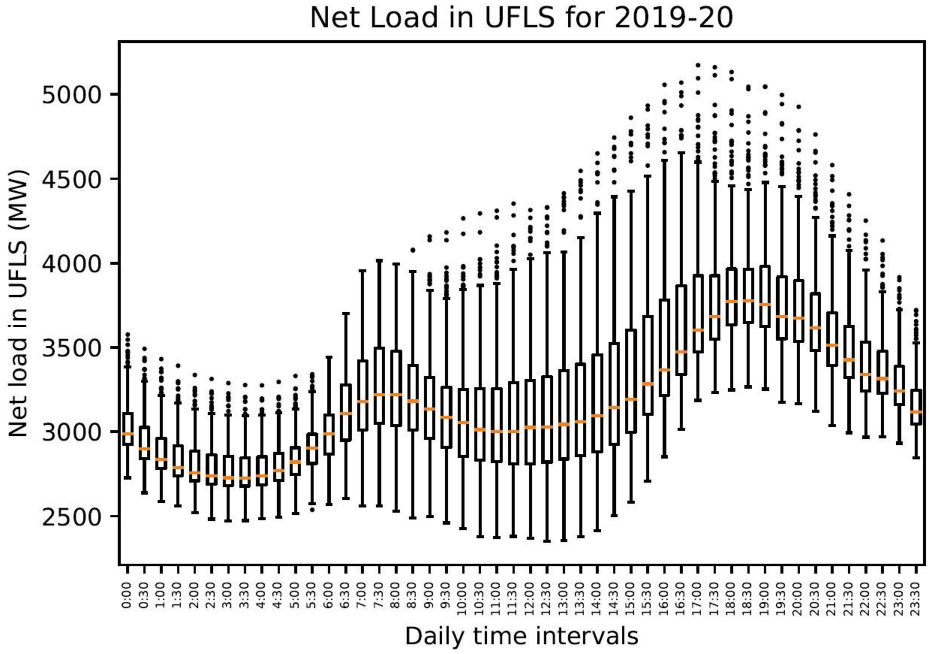


Figure 4 shows the distribution of net UFLS load by time of day, for the 2019-20 historical year. The orange bars indicate the median load level measured at each time of day during 2019-20. The lowest median net UFLS load occurs during night time periods (2am-4am). The outer bars indicate the maximum and minimum demand levels (excluding outliners) measured at each time of day. The absolute minimum net UFLS load levels were measured during the middle of the day (12pm-2pm), although there is a wide range of load measured in these periods due to different DPV generation patterns on different days. This highlights the increasing variability of the amount of net load in the UFLS scheme, as DPV levels grow over time.

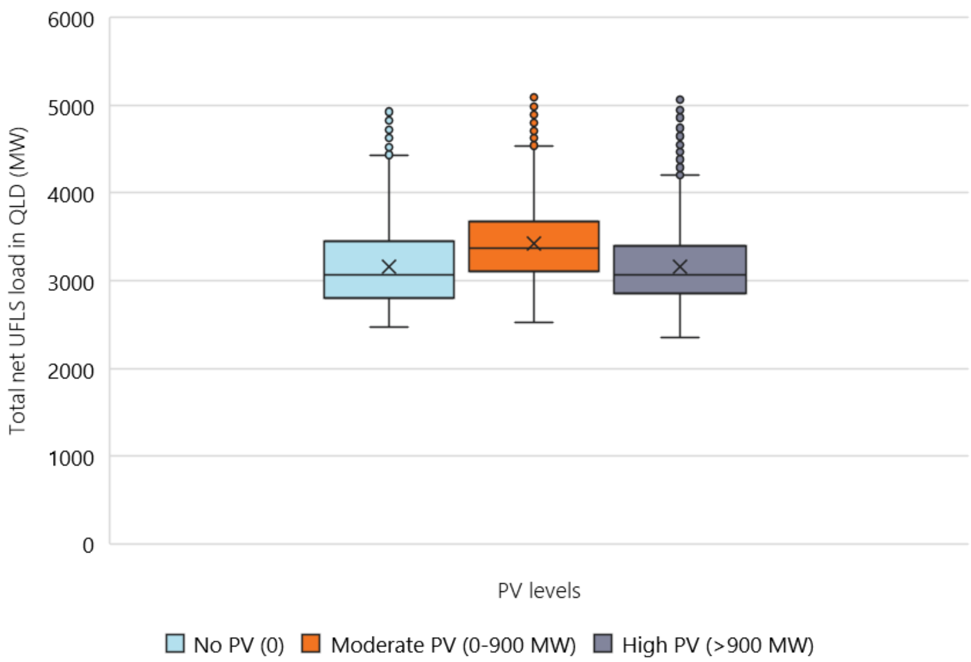
Figure 4 Queensland distribution of net UFLS load in 2019-20



Orange bar: median. Top bar: max demand, excluding outliers. Bottom bar, min demand, 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 5 shows a box and whisker plot of the total net load in the Queensland UFLS, divided into periods with no DPV operating, periods with moderate DPV operating (total Queensland DPV generation in the range 0 MW to 900 MW), and periods with high levels of DPV operating (total Queensland DPV generation exceeding 900 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 5 Queensland total net UFLS load in 2019-20

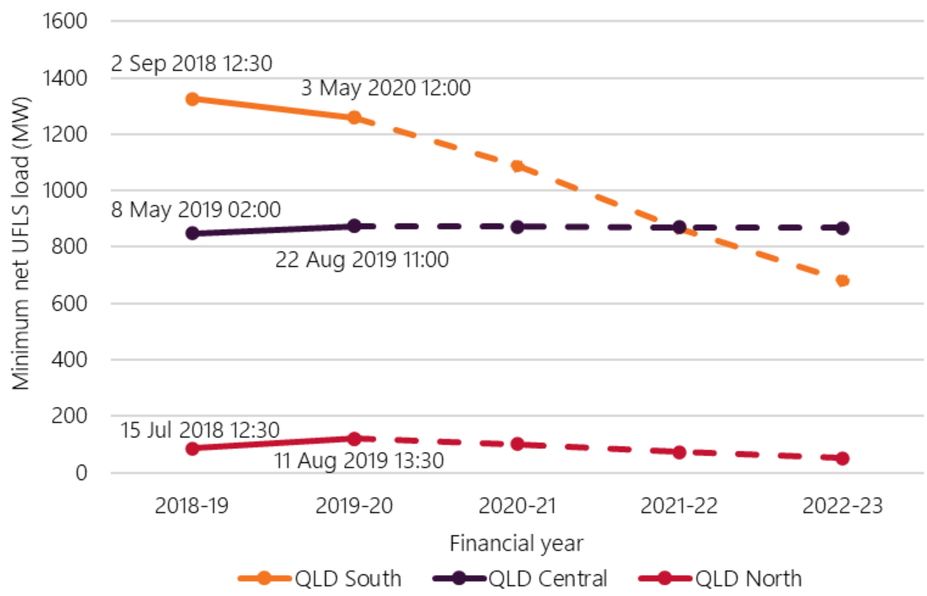


3.1.1 Queensland Sub-regions

Figure 6 shows the minimum net UFLS load measured in the UFLS scheme for Queensland South, North and Central sub-regions for 2018-19 and 2019-20, and projections for the subsequent [3] years. The following observations can be made:

- In QLD South, the minimum UFLS load decreased from 1,325 MW in 2018-19 to 1,260 MW in 2019-20. This trend is projected to continue, with minimum UFLS load potentially reaching as low as 1,088 MW during 2020/21, and 682 MW during 2022/23.
- In QLD Central, the minimum UFLS load increased from 849 MW in 2018-19 to 875 MW in 2019-20. The 2018-19 minimum occurred at night (8 May 2019 02:00), whilst the 2019-20 minimum occurred during the day (22 Aug 2019 11:00). The Central sub-region has a high proportion of industrial customers. During both historical periods, 90%-95% of the UFLS was continuously made up of large industrial load. The analysis presented here assumes no further growth in underlying load at these industrial customers, as per assumptions in the 2021 ESOO. In 2019-20 only 15% of the total DPV installed in QLD Central was on feeders or co-located with customers that are part of the UFLS scheme. If DPV growth continues in areas where there is DPV growth at present, the minimum UFLS load is projected to remain relatively unchanged over the next few years.
- In QLD North, the minimum UFLS load increased from 85 MW in 2018-19 to 121 MW in 2019-20. Industrial load is an important component, contributing up to 51% of total UFLS load in the sub-region. The analysis presented here assumes no further growth in underlying load at industrial customers, as per assumptions in the ESOO. In 2019-20, 37% of the total DPV installed in QLD North was on feeders in the UFLS. The minimum UFLS load is therefore projected to decline slightly over the next few years, if DPV growth continues in the locations where it is growing at present.

Figure 6 Queensland sub-regions minimum net UFLS load in historical and future years



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[4], 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

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

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[5]. 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:

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

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 may 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.

[5] 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

3.2.1 Queensland total

Figure 7 shows the total net UFLS load as a percentage of the total underlying load in Queensland, for the 2019-20 historical year. In periods with no DPV generating, this percentage was close to 60% (in the range 56-62%) the majority of the time. However, in periods with high levels of DPV operating (>900 MW), this percentage was below 60% all of the time. In these high DPV periods, this percentage had a median value of 47%, and in some periods was as low as 41%.

This suggests that the effectiveness of the UFLS in Queensland is now being affected by DPV in some periods and indicates that further analysis is warranted to assess and address the effectiveness of the scheme, particularly in these high DPV periods.

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

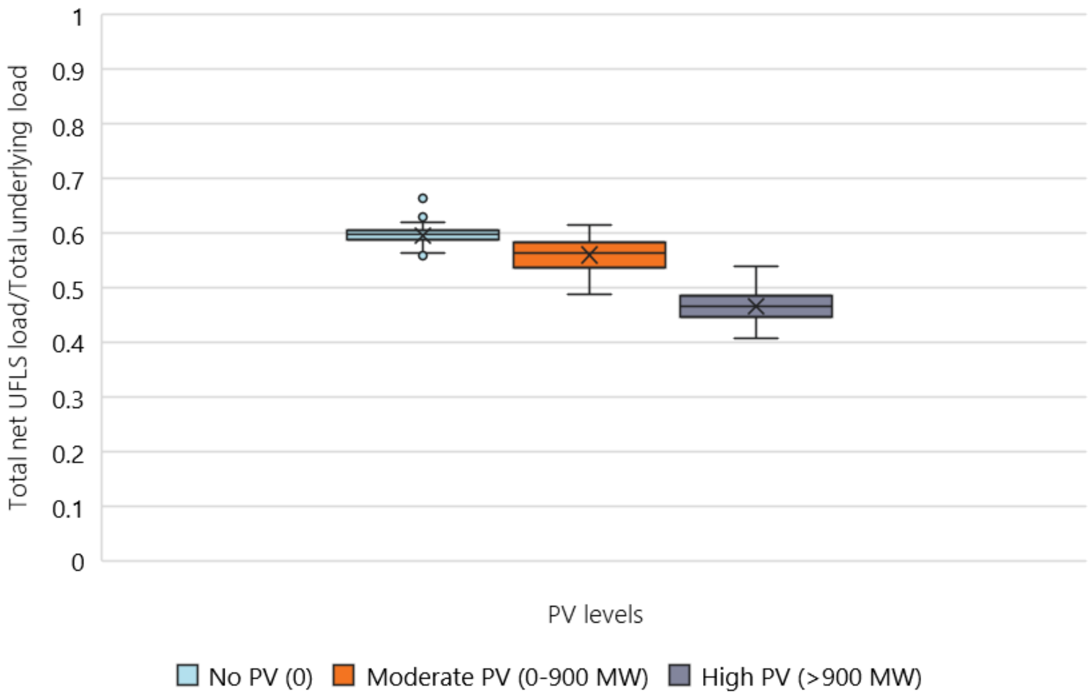


Figure 8 shows the projection of the total net UFLS load as a percentage of total underlying load, projecting forward to 2022-23. By 2022-23, total net UFLS load in Queensland projected to fall as low as 29% of total underlying load in Queensland in some periods with high levels of DPV operating.

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

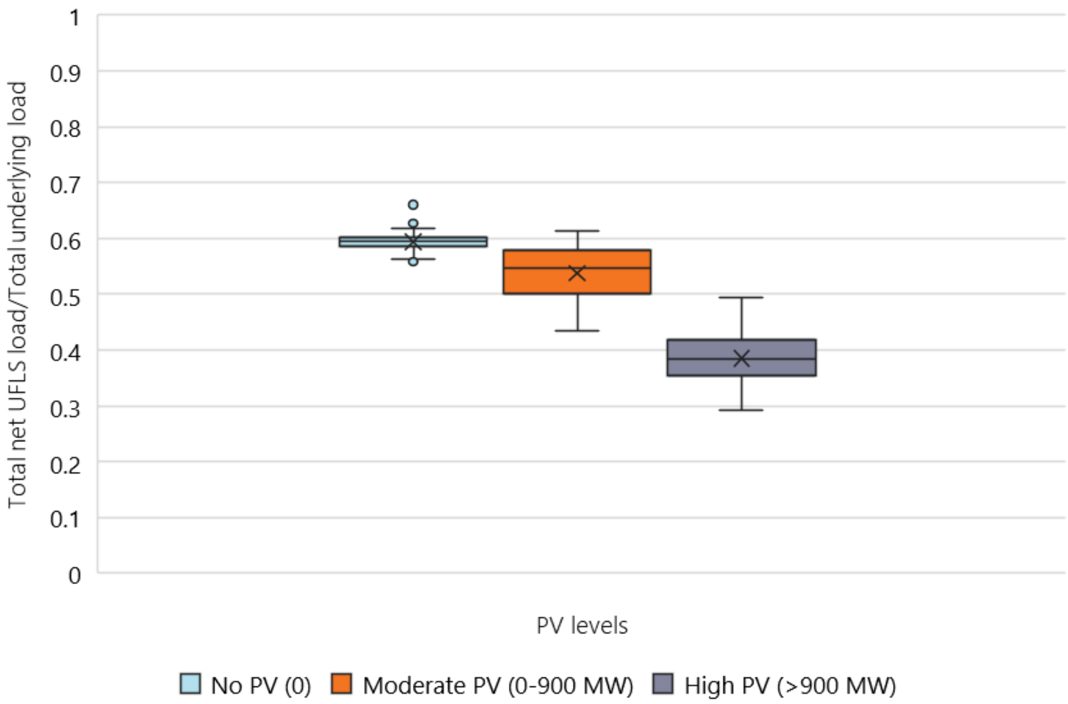


Table 6 provides a summary of historical and forward projection data, showing the minimum net UFLS load as a percentage of the total underlying load in Queensland. This minimum percentage remained at 41% from 2018-19 to 2019-20, however is projected to decline to 29% by 2022-23.

Table 6 Queensland net UFLS load summary

	Historical		Projections – DPV growth rate based on ESOO forecast		
	2018-19	2019-20	2020-21	2021-22	2022-23
Total DPV installed (MW)	2403	2886	3405	4120	4697
Minimum operational load (MW)	3961	3688	3448	3103	2757
Minimum net UFLS load (MW)	2400	2351	2166	1929	1715
Minimum net UFLS load (Minimum % of total underlying load)	41%	41%	37%	33%	29%

3.2.2 Queensland Sub-regions

Table 7 provides a summary of historical and projected net UFLS load in each sub-region, as a proportion of underlying demand.

In the Central sub-region, net UFLS load in 2019-20 ranged from 71-81% of underlying load in periods with no DPV generating, excluding outliers. This is somewhat reduced in periods with high levels of DPV operating, but still remains between 62-75% excluding outliers. This indicates that the Central region, where UFLS load is primarily composed of large industrial customers, is relatively less affected by DPV compared with other Queensland sub-regions.

In the North sub-region, the net load on UFLS was 16%-38% of underlying load in 2019-20. In periods with no DPV generating, the net UFLS load is at the higher end of this range (30-37% of underlying load the majority of the time). In periods with high levels of DPV operating, the net UFLS load is at the lower end of this range (16-31% of underlying load the majority of the time). A low proportion of the net load in the North sub-region is included in the UFLS scheme compared to the other regions. In the North sub-region, only 25-33% of total residential and commercial load is included in the UFLS, and only 32-64% of total industrial load is included in the UFLS. This may suggest an opportunity to improve UFLS effectiveness by adding a larger proportion of this customer load to the scheme.

Table 7 Summary of findings for QLD sub-regions

		QLD South	QLD Central	QLD North	QLD Total
Percentage of time that (Net UFLS load / Underlying load) is less than 60%	2018-19 (Actuals)	95%	0%	100%	86%
	2019-20 (Actuals)	94%	0%	100%	81%
	2020-21 (Projected)	94%	0%	100%	81%
	2021-22 (Projected)	94%	0%	100%	83%
	2022-23 (Projected)	95%	0%	100%	84%
Percentage of time that (Net UFLS load / Underlying load) is less than 55%	2018-19 (Actuals)	38%	0%	100%	38%
	2019-20 (Actuals)	38%	0%	100%	37%
	2020-21 (Projected)	39%	0%	100%	39%
	2021-22 (Projected)	41%	0%	100%	40%
	2022-23 (Projected)	42%	0%	100%	41%
Minimum percentage (Net UFLS load / Underlying load)	2018-19 (Actuals)	36%	61%	12%	41%
	2019-20 (Actuals)	35%	62%	16%	41%
	2020-21 (Projected)	30%	62%	13%	37%
	2021-22 (Projected)	24%	62%	9%	33%

		QLD South	QLD Central	QLD North	QLD Total
	2022-23 (Projected)	18%	61%	7%	29%

3.3 Distributed PV in UFLS

As shown in Table 8, it is estimated that around 53% of the DPV installed in Queensland was connected to feeders included in the UFLS in 2019-20. This estimate has not changed significantly over the previous several years as DPV installation levels have grown.

The proportion of underlying load in the UFLS is typically around 60% (ranging from 56% to 63%, excluding outliers). This has not changed significantly over the past several years.

The similarity in these percentages indicates that the QLD UFLS does not disproportionately include feeders that have higher DPV levels.

Sub-regional observations for 2019-20 are as follows:

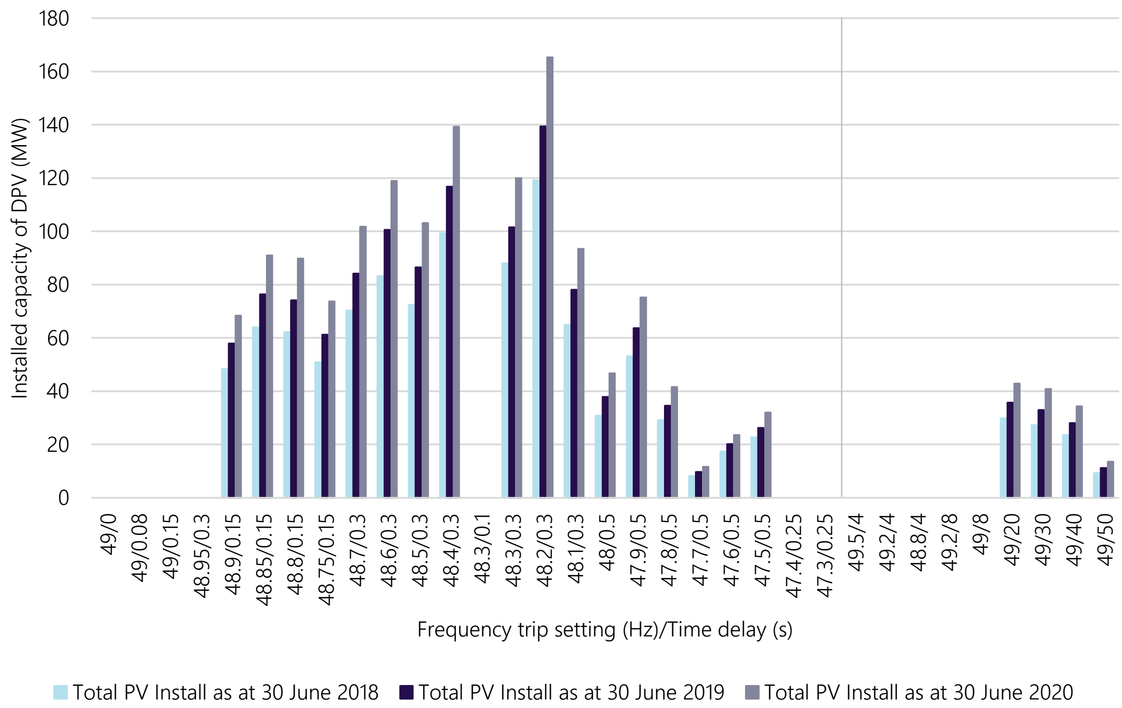
- In the South sub-region, around 59% of the DPV in the sub-region was included in the UFLS, and around 56-65% of the underlying load was included in the UFLS (excluding outliers).
- In the Central sub-region, only 15% of the DPV in the sub-region was included in the UFLS, but 64-85% of the underlying load (excluding outliers). This indicates that in the Central sub-region, UFLS feeders with high levels of DPV tend to be excluded from the UFLS. For the Central sub-region, large industrial customers make up a high proportion of the load in the sub-region.
- In the North sub-region, around 37% of the DPV in the sub-region was included in the UFLS, and around 30-37% of the underlying load was included in the UFLS (excluding outliers).

Table 8 Queensland DPV data summary

	QLD		QLD South		QLD Central		QLD North	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
% of DPV capacity installed in UFLS	53%	53%	58%	59%	18%	15%	37%	37%
% of underlying load in UFLS (range excluding outliers)	54%-63%	56%-63%	55%-62%	56%-65%	62%-85%	64%-85%	27%-39%	30%-37%

Figure 9 shows the distribution of DPV installed capacity across the UFLS stages. The stages with no DPV installed capacity are transmission connected customers. The stages from 48.7 Hz to 48.2 Hz have the largest quantities of DPV installed as at 30 June 2020, and this is continuing to grow each year. The time delays indicated are intentional delay only.

Figure 9 Installed capacity of DPV in Queensland



DPV installed capacities shown are as provided by Energy Queensland and are not scaled up to meet the data from the Clean Energy Regulator.

3.4 Load distribution on frequency stages

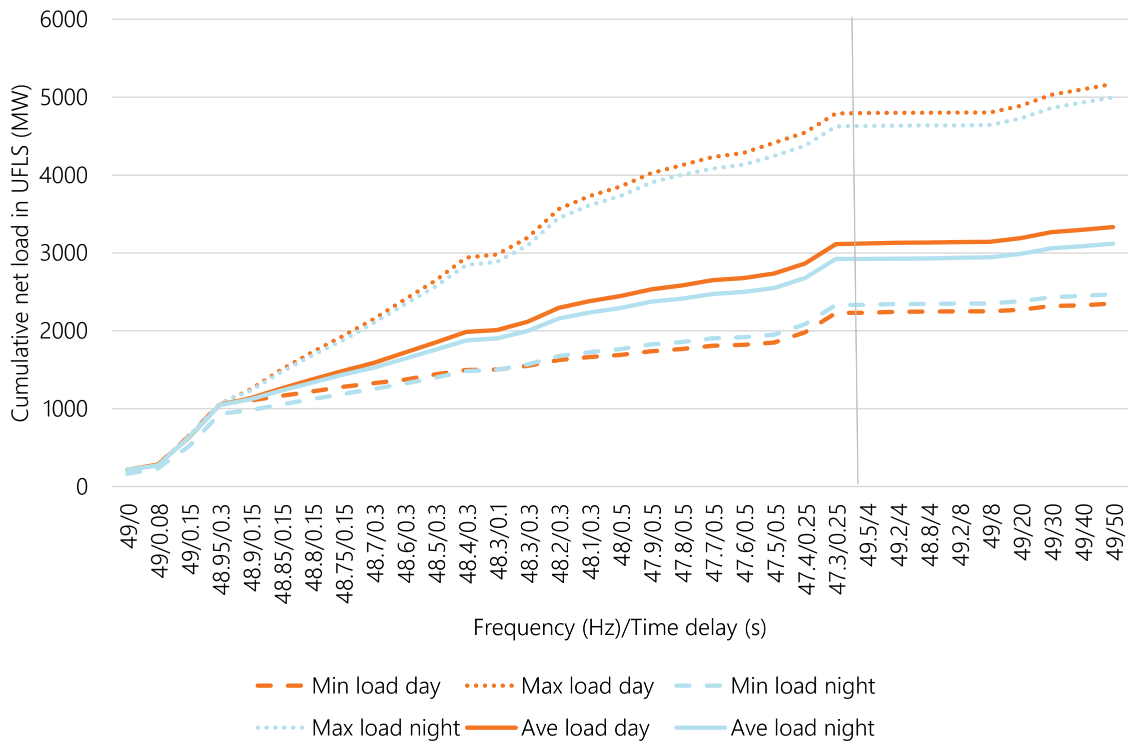
Figure 10 shows the cumulative net load in the Queensland UFLS in 2019-20, spread across the various frequency trip settings. The frequency (Hz) and time delay (seconds) for each UFLS stage are shown along the horizontal axis. The time delays indicated are intentional delay only. As frequency falls, progressively more load will trip to arrest the frequency decline. On the right of the chart, several UFLS stages with longer time delays are shown (4 seconds, 8 seconds, 20 seconds, 30 seconds, 40 seconds and 50 seconds). These stages assist with frequency recovery, if frequency remains low for an extended interval.

Figure 10 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)

The initial stages (above 48.95 Hz) are transmission connected customers that consume load consistently in all time periods. The cumulative net load profile is relatively smooth across the frequency stages for all time periods, and is similar in shape between day and night periods. This suggests that DPV generation affects most load stages in an approximately similar manner.

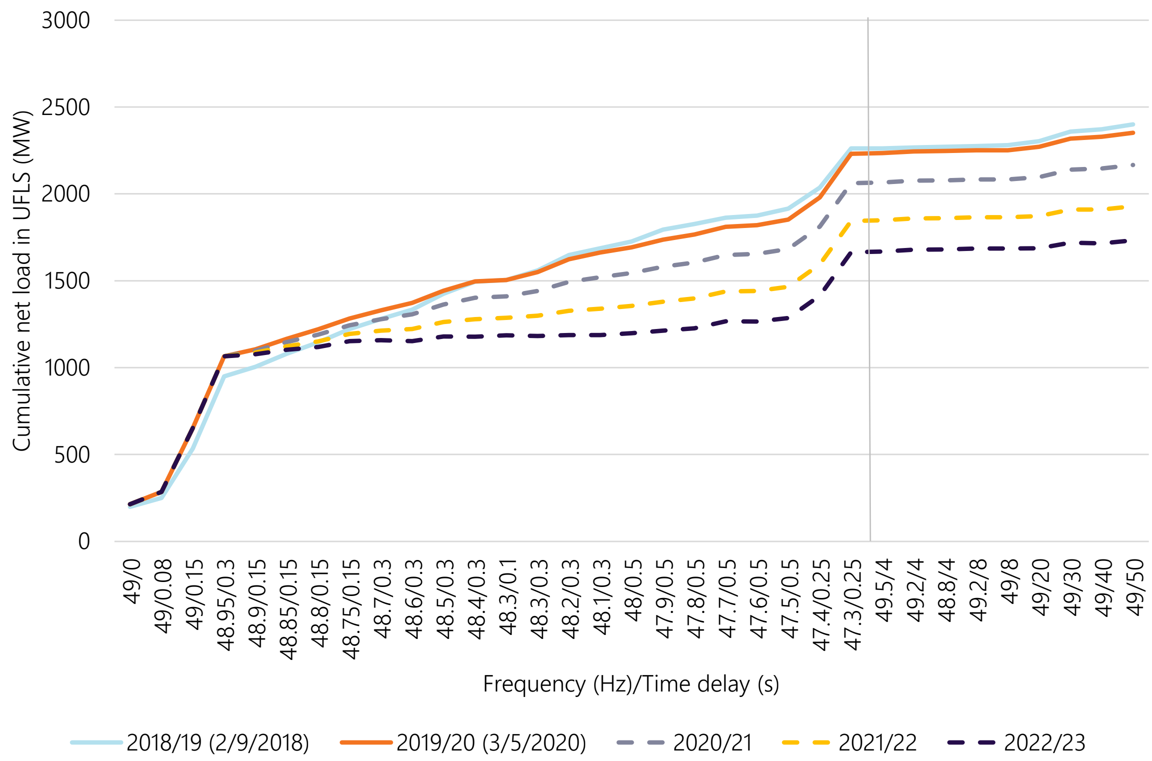
Figure 10 Queensland cumulative net load in UFLS (2019-20)



Time delay settings show the intentional delay only; there will also be an additional measurement delay.

Figure 11 shows the cumulative net UFLS load profile for the minimum UFLS load periods in financial years 2018-19 to 2019-20 and projected forward to 2022-23. Reduction is projected to occur relatively equally across all frequency stages below 48.95Hz.

Figure 11 Queensland cumulative net load in UFLS for minimum load time intervals 2018-19 to 2022-23



3.5 Reverse flows

A selection of UFLS circuits were identified to show reverse flows at significant levels in 2019-20, and on regular occasions (>2% of the time). 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.

In some locations, reverse flows were observed during both daytime and night time periods, and therefore are likely not solely related to DPV. These include:

- On one feeder, reverse flows were identified in some periods up to 4.5 MW, with reverse flows occurring almost 99% of the time. The average level of reverse flows is 1.5 MW.
- On another feeder, reverse flows were identified in some periods up to 3.6 MW, with reverse flows occurring 28% of the time. The average reverse flow is 1.8 MW.
- In the Central sub-region, one transmission connected feeder exhibited reverse flows in some periods up to 8.5 MW, occurring 3.2% of the time. The average reverse flow is 7 MW.

Many additional feeders are also showing periods of reverse flows occurring only in daytime periods, which could be related to the generation of DPV. These were observed throughout Queensland with a particular concentration observed in Townsville. At this stage, reverse flows at these feeders are generally observed less than 2% of the time. This is expected to grow over time as the level of DPV installed grows.

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. In July 2021 the AEMC made a rule to introduce an FFR ancillary service market from October 2023[6].
- **Primary Frequency Response** – scheduled and semi-scheduled generators dispatched above 0MW in the NEM are now required to respond automatically to changes in power system frequency unless

[6] AEMC (15 July 2021) Fast frequency response market ancillary service, https://www.aemc.gov.au/rule-changes/fast-frequency-response-market-ancillary-service

exempt[7]. Scheduled loads (including batteries that are charging) or batteries dispatched at 0 MW are currently 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 primary frequency response is ongoing.

- **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 commenced on 24 October 2021 to allow consumers to sell demand response in the wholesale market, either directly or through aggregators[8]. 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.

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

[8] 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 Remove circuits in frequent reverse flows

As discussed in Section 3.5, this analysis has indicated that there are a number UFLS circuits that are often in reverse flows. This means that normal operation of the UFLS relays at these locations will trip net generation, exacerbating the under-frequency disturbance rather than helping to correct it.

AEMO requests that NSPs investigate the causes of the reverse flow data, confirming validity, and provide suggestions on possible avenues for addressing this. Possibilities may include the following:

- Removing the affected circuits from the UFLS scheme, and replacing them with less affected circuits.
- Dynamically arming UFLS relays, so that they automatically disarm when the circuit is in reverse flows.
- Developing an arrangement such that loads on the circuit are tripped by UFLS relays, but the generation remains connected.

AEMO requests that NSPs explore the available options, and inform AEMO of their recommended approach.

In addition to considering the remediation of existing sites where generators are affecting the UFLS scheme, it would also be beneficial to understand potential approaches to managing new generator connections, such that these would not be connected in a manner that reduces UFLS effectiveness. AEMO is also seeking NSP suggestions on how this should be managed.

4.2 Active monitoring of UFLS load

As noted in Section 0, the amount of total load on the Queensland UFLS is reducing, and in the coming years will reduce below the indicative levels suggested by the NER.

So that this can be actively monitored, it may be beneficial to establish a real-time SCADA feed of total net UFLS load in Queensland (and possibly for each sub-region). 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.

AEMO is seeking advice from NSPs on the options, technical and economic feasibility, and potential barriers for implementing real-time monitoring of the total net UFLS load in Queensland.

4.3 Address DPV impacts

As discussed in Section 3.5, there are now some UFLS circuits in the UFLS that appear to be demonstrating reverse flows at certain times related to high levels of DPV generation. Furthermore, total net load on the UFLS is already below the levels indicatively suggested in the NER, in periods with high levels of DPV generation, and is expected to continue to reduce.

This suggests that it would be timely to start exploring options for addressing DPV impacts. Without ruling out other possibilities, options may include some combination of the following:

Table 9 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.
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.
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.

Some of these options may have long lead times for implementation, and therefore need to be considered early.

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, and their technical feasibility, approximate costs, and any other relevant barriers or factors.

4.4 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.

A1. 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