Phase 1 UFLS Review: Victoria

August 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 Victoria, 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	3/08/2021	Release to Victorian DNSPs
1.1	15/09/2021	Confidential data removed for public release

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 Victorian 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 Victoria, 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

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.

- The annual minimum total net load in the Victorian UFLS scheme has decreased from 1,926 MW in 2018 to 1,273 in 2020. This trend is projected to continue as the installation of distributed PV (DPV) continues, with minimum UFLS load potentially reaching close to 1,000 MW by late 2021, and 500 MW by late 2023.
- AEMO assessed the total net load in the Victorian UFLS scheme as a percentage of the total underlying load in Victoria, for the 2020 historical year.
  - 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. 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[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). The net load in the UFLS (being the amount of load available to provide an effective

[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

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.

- This analysis indicates that net load in the Victorian UFLS scheme is often below 60% of underlying load during periods with high DPV generation:
  - For the 2020 year, in periods with no DPV generating, net UFLS load remains above 60% of underlying load most of the time, with only a few outliers below the 60% level.
  - However, in the 2020 year overall, net UFLS load was below 60% of underlying load for about a third of the time, and in some periods it was as low as 30%. In periods with high levels of DPV generating (>1000 MW), this percentage is below 60% for more than 99% of the time.
  - By 2023, this percentage is projected to be under 60% for almost 40% of the time, and in some periods the net UFLS load could be as little as 12% of underlying customer load.
- A number of UFLS circuits were observed in reverse flows in 2020, including some examples demonstrating significant reverse flows:
  - On one 66kV sub-transmission loop, reverse flows were identified in some periods exceeding 170 MW, and occurring around 40% of the time.
  - On another 66kV sub-transmission loop, reverse flows were identified as high as 50 MW, with reverse flows occurring more than 60% of the time.
  - This is likely associated with large wind and solar farms connected to these sub-transmission loops. AEMO has confirmed with the NSPs involved that the operation of UFLS relays associated with these sub-transmission loops will trip these large generating units.
  - 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.
- Some sub-transmission loops are also showing periods of reverse flows most likely related to the generation of DPV. Some of these sub-transmission loops are showing reverse flows around 5-10 MW in the lowest load periods, and showing reverse flows up to 2.5% of the time.

Next steps

This analysis demonstrates that net load in the Victorian UFLS scheme is decreasing due to continuing growth in DPV. It has also identified that the connection of large generating units (in the range of 10 - 120 MW) in UFLS circuits has occurred, and this reduces UFLS effectiveness.

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 well 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 is operating without the intended safety nets, placing customers at unacceptable risk.

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 Victorian NSPs, the Victorian Jurisdictional System Security Coordinator (JSSC), and the Victorian Electricity Emergency Committee (VEEC) 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 the adverse impact of large generating units on the UFLS scheme**. Specific locations where AEMO has identified this issue are listed in Section 3.5, and AEMO is seeking NSP advice on other possible locations that may be similarly affected. AEMO is also seeking high level advice on the technical and economic feasibility of the following possible remediation approaches, and any others suggested by NSPs:
  - Removing the affected sub-transmission loops from the UFLS scheme, and replacing them with loads at other locations.
  - Dynamically arming UFLS relays, so that they automatically disarm when the circuit is in reverse flows, or based on other SCADA signals as appropriate.
  - Moving UFLS relays to a lower voltage level (within sub-transmission loops), so that loads on the loop are tripped by UFLS relays, but the large-scale generation remains connected.
  - Or any combination of the above approaches, on a case-by-case basis.
- **Introducing active monitoring of UFLS load**, including the possibility of establishing a real-time SCADA feed for total net Victorian UFLS load.
- **Addressing DPV impacts**, such that sufficient net UFLS load is maintained as DPV levels grow over the coming years. AEMO is seeking high level advice on the technical and economic feasibility of remediation approaches. Some suggestions are below, and AEMO also seeks advice on 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 will likely need to become a "business as usual" activity.
  - Removing sub-transmission loops 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.
  - Moving UFLS relays to a lower voltage level (to be considered on a case-by-case basis for specific sites, where DPV installations are not uniform)
  - 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).
  - Consider approaches to management of sub-transmission loops that may have minimal net load at times of high DPV generation, and possible approaches to limit unnecessary disconnection of customers where disconnection of the feeder does not provide much benefit to arrest a frequency decline.

AEMO 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

Executive summary **3**

1. Introduction **8**

2. Approach **12**

3. Findings **14**

3.1 Net load in UFLS 14

3.2 Net load in UFLS as a percentage of underlying load 17

3.3 Distributed PV in UFLS 19

3.4 Load distribution on frequency stages 21

3.5 Reverse flows 23

4. Next Steps **25**

4.1 Remove large generating units from UFLS 25

4.2 Actively monitor UFLS load 26

4.3 Address DPV impacts 26

4.4 Further work 27

Glossary **28**

Tables

Table 1 Key AEMO responsibilities relating to UFLS 8

Table 2 Key NSP responsibilities relating to UFLS 9

Table 3 Key JSSC responsibilities relating to UFLS 10

Table 4 Key Market Customer responsibilities relating to UFLS 11

Table 5 Net UFLS load summary 19

Table 6 DPV data summary 19

Table 7 Large solar and wind generators on UFLS circuits (CONFIDENTIAL) Error! Bookmark not defined.

Figures

Figure 1 UFLS load duration curves in historical and future years 14

Figure 2 UFLS load duration curves in historical and future years (80% - 100%) 14

Figure 3	Minimum net UFLS load in historical and future years	15
Figure 4	Distribution of net UFLS load in 2020	16
Figure 5	Total net UFLS load in 2020 under three DPV scenarios	17
Figure 6	Total net UFLS load over total underlying load in 2020 (Actuals)	18
Figure 7	Total net UFLS load over total underlying load in 2023 under three PV scenarios (Projected)	19
Figure 8	Underlying load in UFLS over total underlying load in 2020 under three PV scenarios	20
Figure 9	Installed capacity of DPV in Victoria	21
Figure 10	Cumulative net load in UFLS (2020)	22
Figure 11	Cumulative net load in UFLS for minimum load time intervals	23
Figure 12	Sub-transmission loops in reverse power flows (CONFIDENTIAL)	24

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	AEMO responsibility
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 Victoria. 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. 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[2] (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[3]. 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.

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 2, JSSCs in Table 3, and Market Customers in Table 4.

Table 2 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).

[2] Distributed PV includes rooftop systems and other smaller non-scheduled PV capacity.

[3] 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

NER clause	NSP responsibility
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;
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 3 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 4 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 Victoria (AusNet, Powercor, CitiPower, Jemena and United Energy) during 2020 to construct the necessary datasets for this analysis, as outlined in the sections below.

Half-hourly load data

In Victoria, most UFLS relays are located at the 66kV level. These UFLS relays trip "sub-transmission loops" of network. The locations of the UFLS relays align closely with the locations of transmission use of system (TUoS) metering in the Victorian network. As AEMO has direct access to this TUoS metering, it was possible for AEMO to extract and aggregate half-hourly load measurements to estimate the total amount of load in the UFLS at each frequency trip setting, in each half hour.

AusNet provided a mapping to AEMO indicating which TUoS National Metering Identifier (NMI) was associated with each sub-transmission loop. These sub-transmission loops could then be matched against the UFLS settings schedules to determine the trip frequency and delay time settings associated with each load. AEMO was then able to extract historical half-hourly operational load data for calendar years 2018 to 2020 from sub-transmission (66kV) TUoS metering, and sum this to determine the total amount of load at each trip setting, in each historical half hour.

Large industrial customers

A number of large industrial customers are included in the UFLS schedule. Most of these are captured in the sub-transmission NMI measurements outlined above. For a small number of industrial customers that are not included in these estimates, the half-hourly load associated with these customers was extracted from AEMO's SCADA systems, and added to the total UFLS load in each time period.

Installed capacity of DPV

The installed capacity of DPV on each sub-transmission loop was also estimated. The NSPs provided a mapping of individual customer NMIs to sub-transmission loops, and this was matched against the DER Register[4] (providing the installed capacity of DPV associated with each customer NMI). This allowed estimation of the total capacity of DPV associated with each sub-transmission loop.

The quality of the DER Register data was found to be relatively poor. A range of data cleaning approaches was applied:

- Entries that were internally inconsistent were corrected.
- Some NSPs provided datasets on the installed capacity of DPV, which could also be used to compare with the DER register data.
- Total DPV was summed on a postcode by postcode basis, and compared with the postcode datasets published by the Australian PV Institute (APVI). This comparison was further used to identify incorrect entries. A scaling was applied to individual DPV system capacities, so that the total postcode values matched those in the APVI dataset. These were then mapped back to sub-transmission loops to estimate total DPV capacity installed on each loop.

For this assessment, the half-hourly generation of DPV associated with each sub-transmission loop was estimated for the historical 2018 to 2020 period based on the estimated generation of DPV across Victoria in

[4] This is the register of distributed energy resources (DER) information established by AEMO under rule 3.7E of the NER.

the time period (based on AEMO's DPV forecasting system, ASEFS2[5]), scaled according to the proportion of regional DPV installed on each sub-transmission loop.

Future projections

This assessment includes some simple forward projections of UFLS load for calendar years 2021 to 2023, assuming continued growth in DPV installations. To calculate these forward projections, future DPV installation growth rates were taken from the High DER scenario in AEMO's Electricity Statement of Opportunities (ESOO)[6]. 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 in the 2020 year in each half hour was estimated as:

Underlying load 2020 = Net load 2020 + PV generation 2020

The half-hourly underlying load in future years was assumed to remain identical to the 2020 reference year (broadly consistent with ESOO projections). 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 sub-transmission loop was then calculated as:

Net load 2022 = Underlying load 2020 - PV generation 2022

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

[5] 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

[6] AEMO (August 2020) 2020 Electricity Statement of Opportunities, https://aemo.com.au/-/media/files/electricity/nem/planning_and_forecasting/nem_esoo/2020/2020-electricity-statement-of-opportunities.pdf?la=en&hash=85DC43733822F2B03B23518229C6F1B2

3. Findings

3.1 Net load in UFLS

Figure 1 shows a duration curve of the total net (measured) load in the Victorian UFLS scheme in calendar years 2018, 2019 and 2020. Indicative future projections for 2021, 2022 and 2023 are also shown. In historical years, total Victorian UFLS load has reached a maximum of 6,168 MW and a minimum of 1,273 MW, and most of the time is within the range 2,000 – 4,000 MW.

Figure 1 UFLS load duration curves in historical and future years

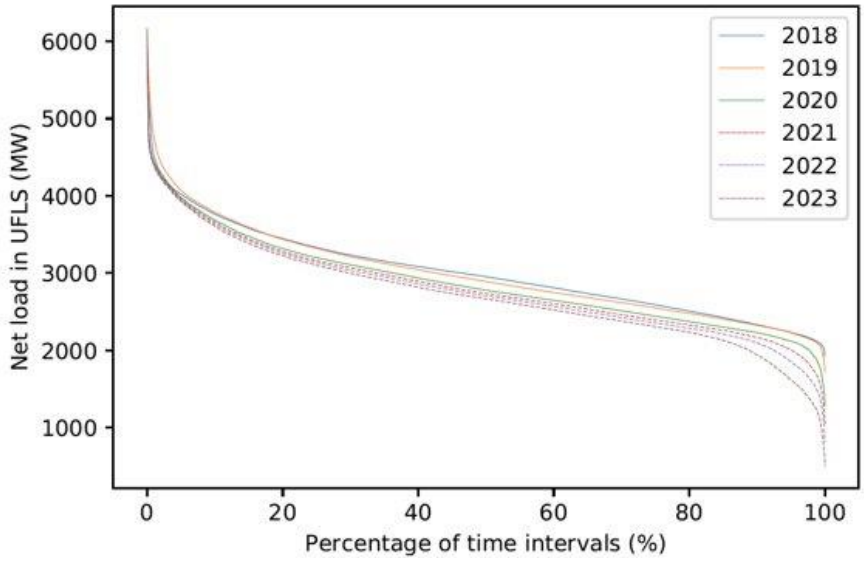


Figure 2 shows the same duration curve, focusing on the year-by-year changes in the lowest load periods. This shows that net UFLS load in Victoria has been decreasing over the past few years in the lowest 20% of periods, and this trend is projected to continue as DPV installations continue to grow.

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

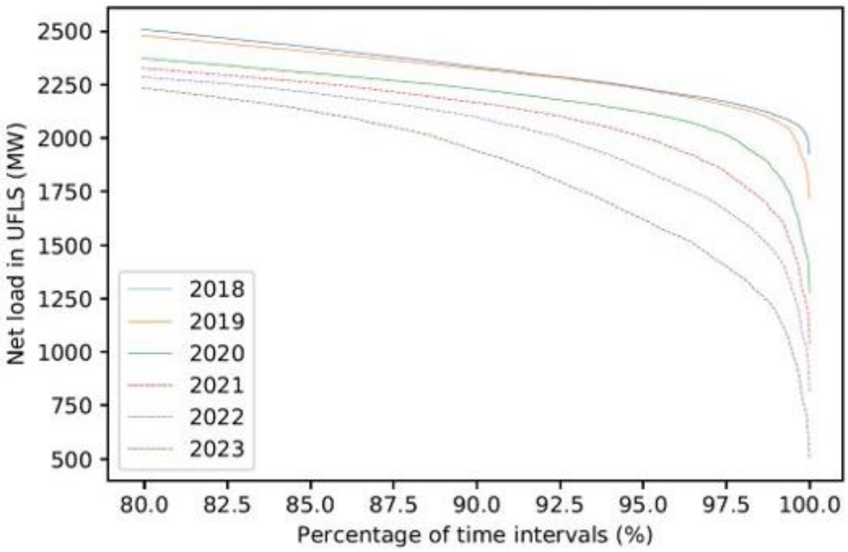


Figure 3 shows the minimum net UFLS load measured in the Victorian UFLS scheme over the past few years. The annual minimum period occurred on 14 January in 2018, 22 December in 2019, and Christmas Day in 2020. The annual minimum UFLS load has decreased from 1,926 MW in 2018 to 1,273 in 2020.

This trend is projected to continue, with minimum UFLS load potentially reaching as low as 1,028 MW by late 2021, and 499 MW by late 2023.

Figure 3 Minimum net UFLS load in historical and future years

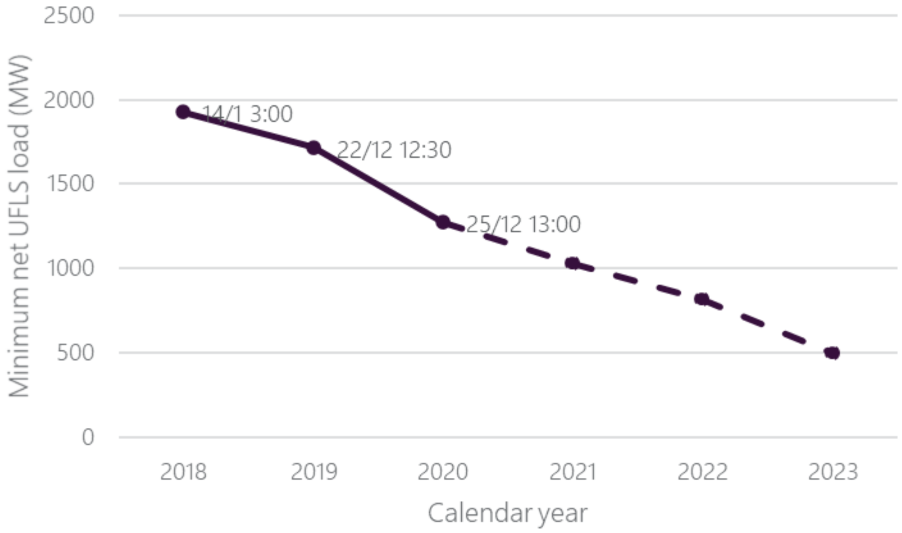
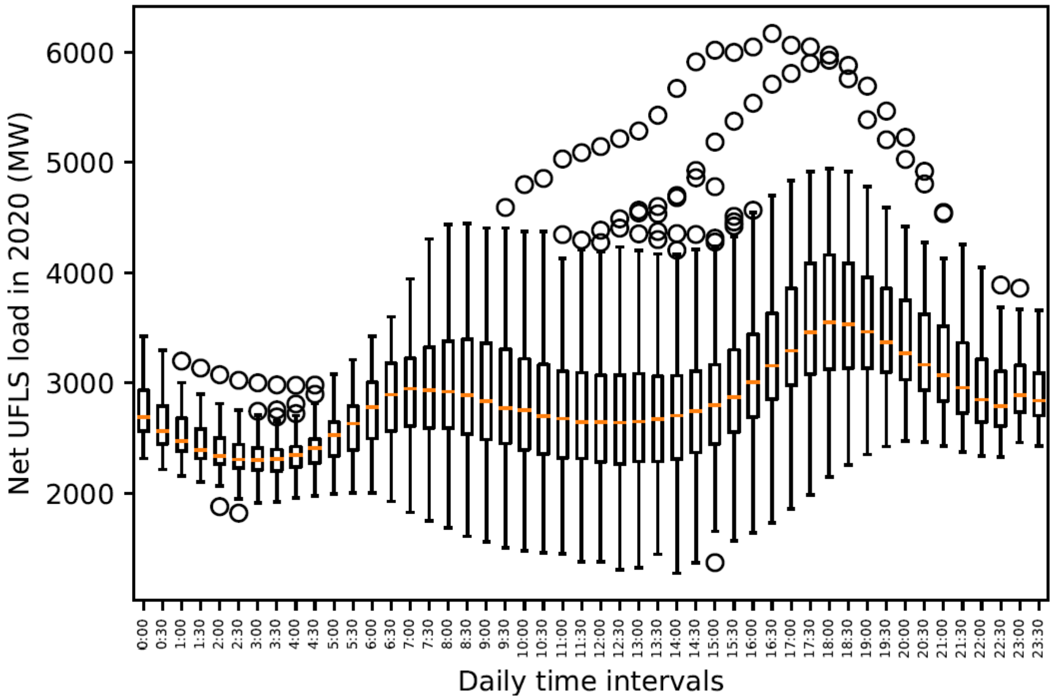


Figure 4 shows the distribution of net UFLS load by time of day, for the 2020 historical year. The orange bars indicate the median load level measured at each time of day during 2020. The lowest median net UFLS load occurs during night time periods (2am-4am). The outer bars indicate the maximum and minimum net 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.

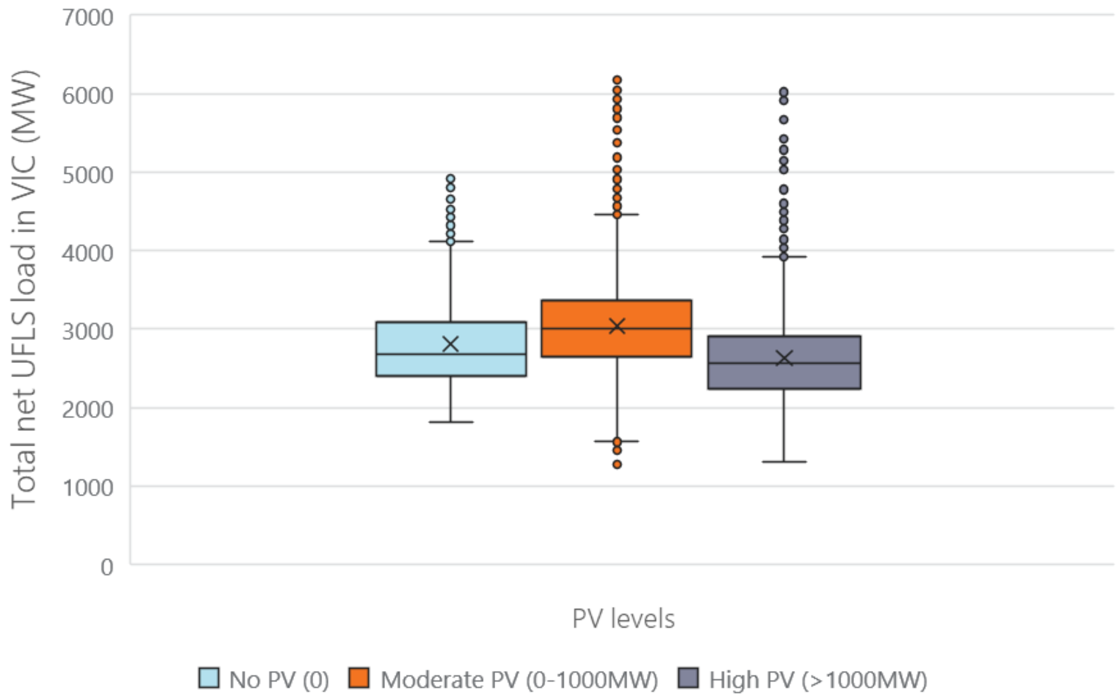
Figure 4 Distribution of net UFLS load in 2020



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 Victorian UFLS, divided into periods with no DPV operating, periods with moderate DPV operating (total Victorian DPV generation in the range 0 MW to 1,000 MW), and periods with high levels of DPV operating (total Victorian DPV generation exceeding 1,000 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 Total net UFLS load in 2020 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)).

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 section 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.

Figure 6 shows the total net UFLS load as a percentage of the total underlying load in Victoria, for the 2020 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 generating, this percentage is now below 50% for more than half the time, and in some periods is as low as 30%.

This indicates that the UFLS in Victoria is now being materially affected by DPV in some periods, and that further analysis is warranted to confirm the extent to which this reduces the scheme's effectiveness of the scheme, particularly in these high DPV periods. Potential remediation methods need to be explored.

Figure 6 Total net UFLS load over total underlying load in 2020 (Actuals)

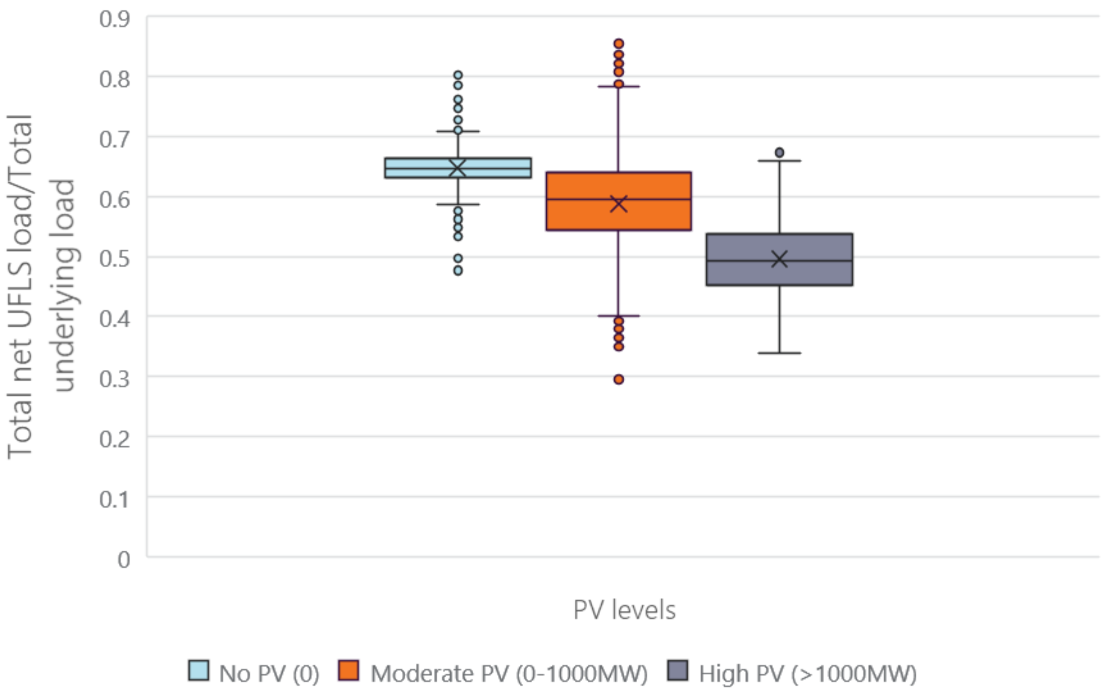


Figure 7 shows the projection of the total net UFLS load as a percentage of total underlying load, projecting forward to 2023. By 2023, this percentage is projected to fall below 60% for almost 40% of the time (and almost all of the time in periods with high DPV generation), and in some periods could be as low as 12%.

Figure 7 Total net UFLS load over total underlying load in 2023 under three PV scenarios (Projected)

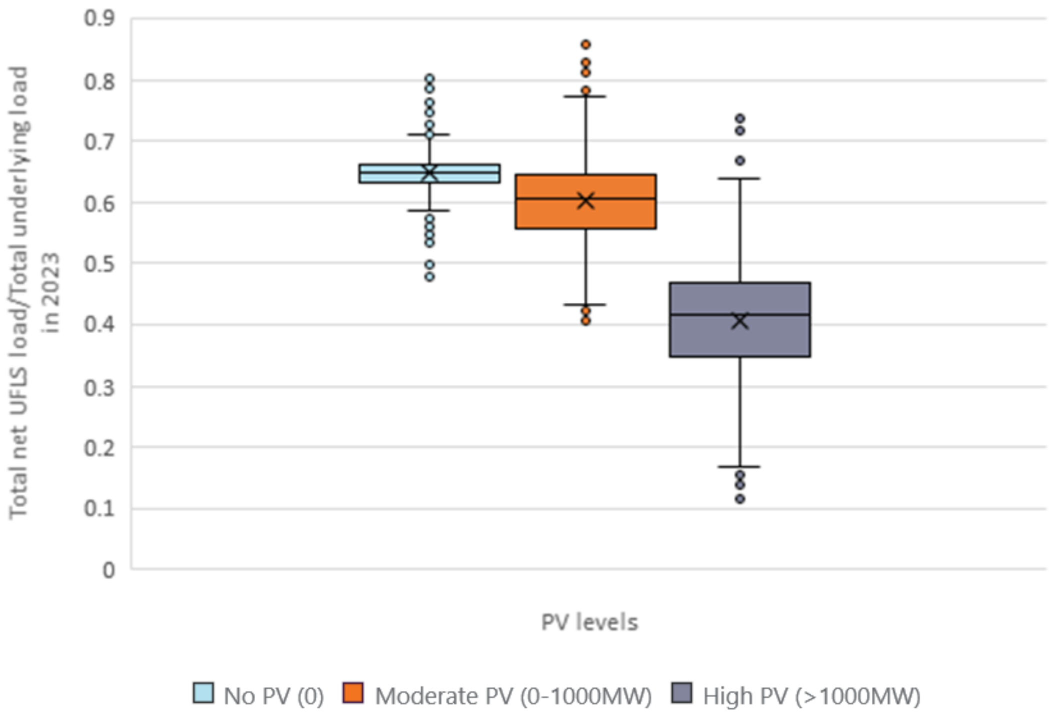


Table 5 provides a summary of historical and forward projection data, showing the minimum net UFLS load as a percentage of the total underlying load in Victoria. This minimum percentage has declined from 41% in 2018 to 30% in 2020, and is projected to decline further to just 12% by 2023.

Table 5 Net UFLS load summary

	Historical			Projections – DPV growth from ESOO High DER scenario		
	2018	2019	2020	2021	2022	2023
Total DPV installed in VIC (MW)	1643	2170	2397	3014	3623	4246
Minimum operational load in VIC (MW)	3085	2821	2090	1713	1378	898
Minimum net UFLS load in VIC (MW)	1926	1716	1273	1028	811	498
Minimum net UFLS load (Minimum % of total underlying load)	41%	33%	30%	24%	19%	12%

3.3 Distributed PV in UFLS

As shown in Table 6, it is estimated that around 65% of the DPV installed in Victoria is connected to sub-transmission loops included in the UFLS. This proportion has not changed significantly over the past three years as DPV installation levels have grown.

Table 6 DPV data summary

	2018	2019	2020
Total installed capacity of DPV in UFLS (MW)	1050	1417	1560
Total installed capacity of DPV in Victoria (MW)	1639	2170	2397

	2018	2019	2020
% of DPV capacity installed in UFLS	64%	65%	65%

This can be compared with the proportion of total underlying load in Victoria that is included in the UFLS, as shown in Figure 8. The ratio of total underlying load in the UFLS compared with the total underlying load in Victoria varies somewhat period to period, but as shown in Figure 8 is typically around 65% (and can range from 45% to 90% in outlying periods). The percentage of DPV installed on circuits involved in the UFLS is roughly similar to the percentage of underlying load on circuits involved in the UFLS. This suggests that circuits involved in UFLS in Victoria are not disproportionately affected by DPV.

Figure 8 Underlying load in UFLS over total underlying load in 2020 under three PV scenarios

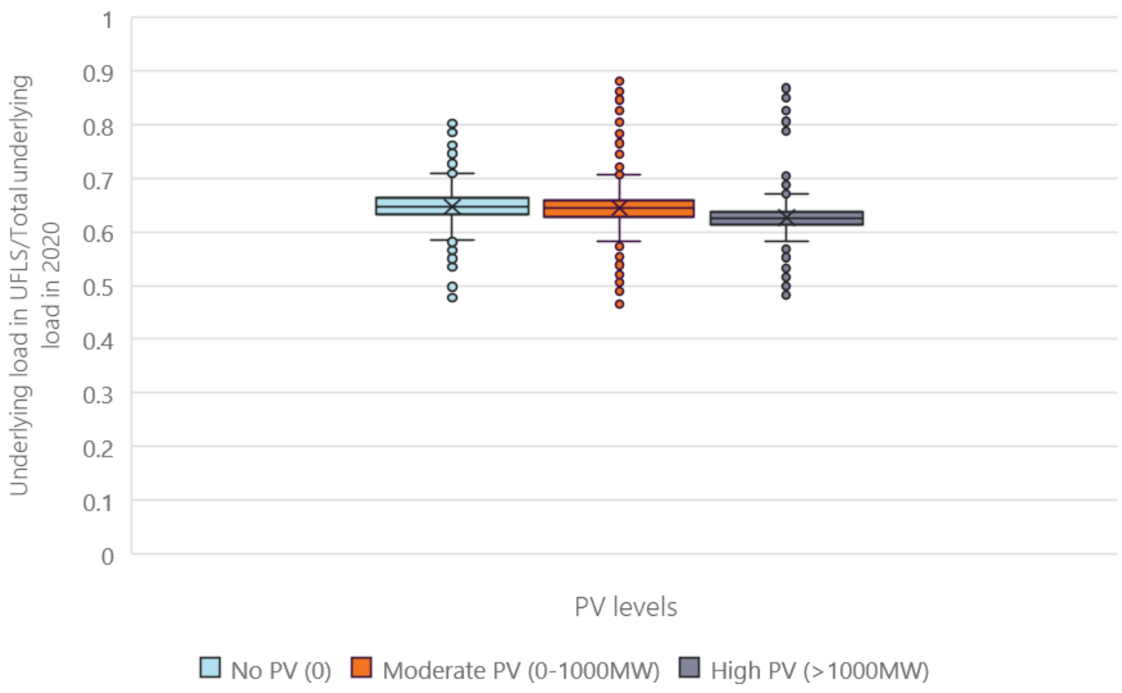
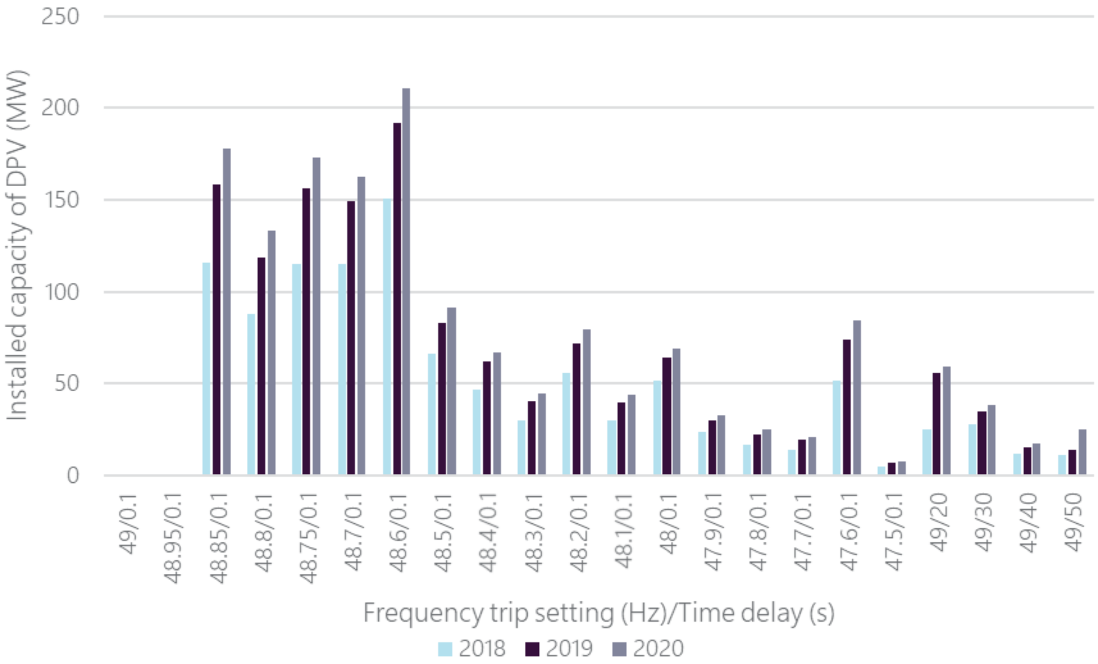


Figure 9 shows the distribution of DPV installed capacity across the UFLS stages. The earlier stages (above 48.5Hz) have the largest quantities of DPV installed, and this is continuing to grow each year.

Figure 9 Installed capacity of DPV in Victoria



3.4 Load distribution on frequency stages

Figure 10 shows the cumulative net load in the Victorian UFLS, spread across the various frequency trip settings. The frequency (Hz) and time delay (seconds) for each UFLS stage are shown along the horizontal axis. 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 (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)

For all time periods, the cumulative net load profile is relatively smooth across the frequency stages. This suggests that DPV generation affects all load stages in an approximately similar manner, and has not resulted in certain stages reducing faster than others.

Figure 10 Cumulative net load in UFLS (2020)

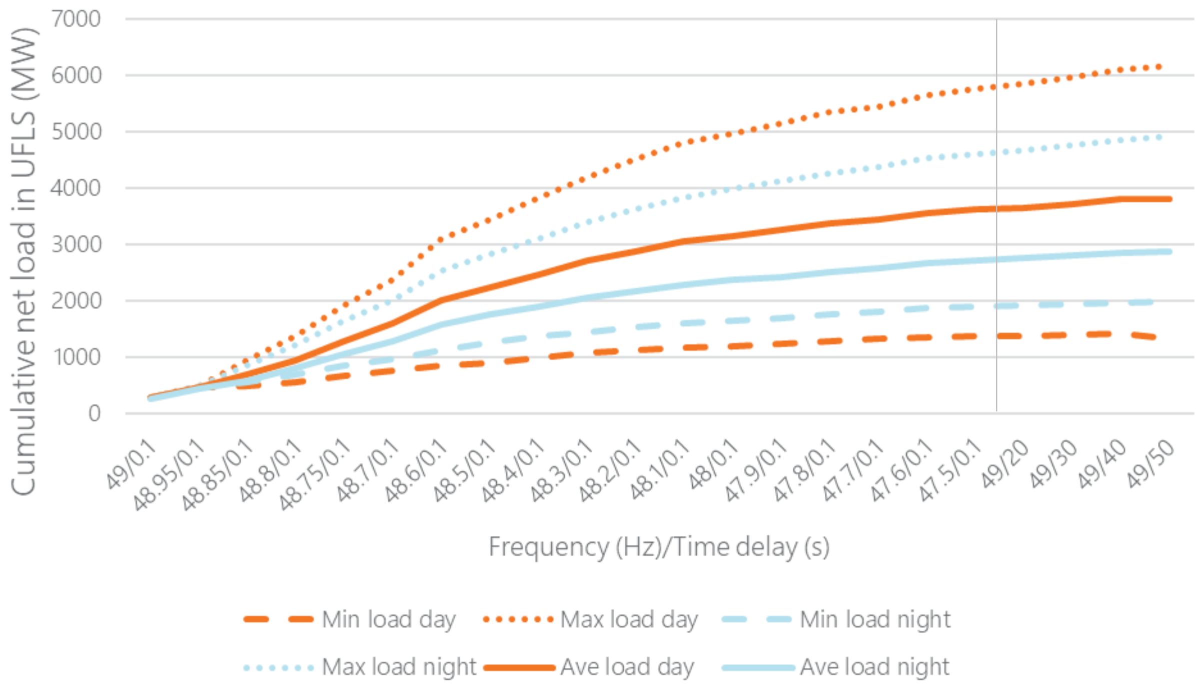
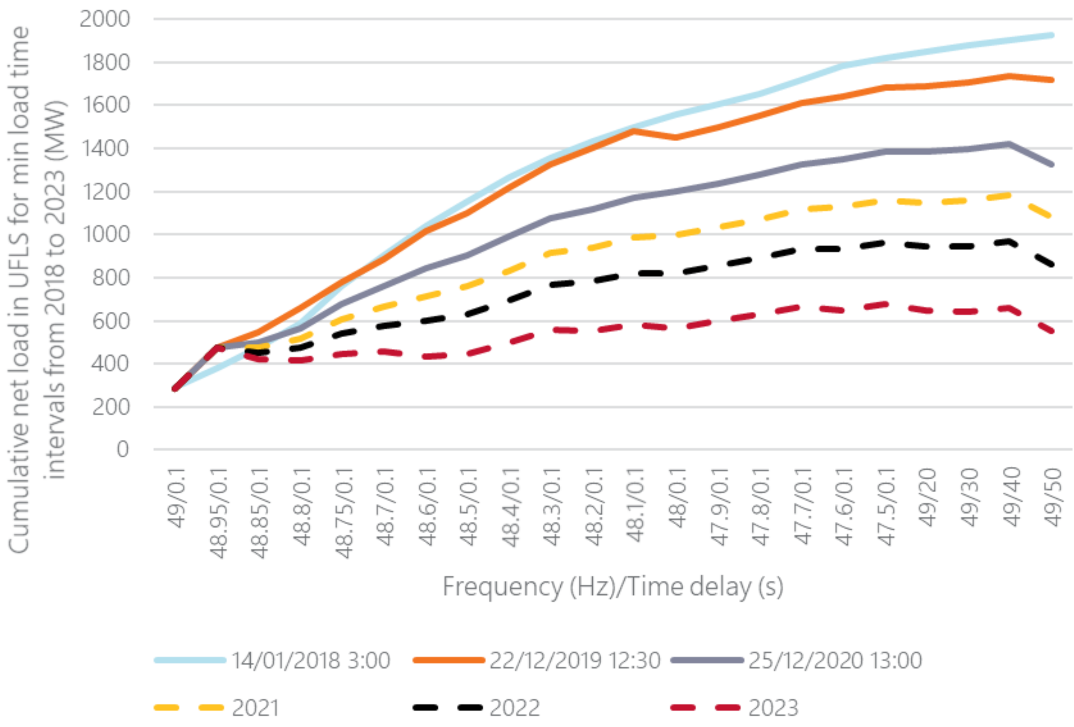


Figure 11 shows the cumulative net UFLS load profile for the minimum UFLS load periods in calendar years 2018 to 2020, and projected forward to 2023. Reverse flows are starting to become apparent in some UFLS stages in these minimum load periods, indicated by the cumulative load curve sloping downwards from left to right. In 2020 this is most apparent in the longer time delay stages. By 2023, reverse flows can be seen extensively across many UFLS stages, including some early stages.

If left unaddressed, UFLS relays will act to trip circuits in reverse flows, which will exacerbate a frequency decline rather than helping to correct it. This can be addressed by introducing dynamic arming of UFLS relays (dynamically disarming relays when the circuit is measured to be in reverse flows). This may require replacement of relays, if the existing relays cannot be reprogrammed with this capability. This is discussed further in Section 3.5.

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



3.5 Reverse flows

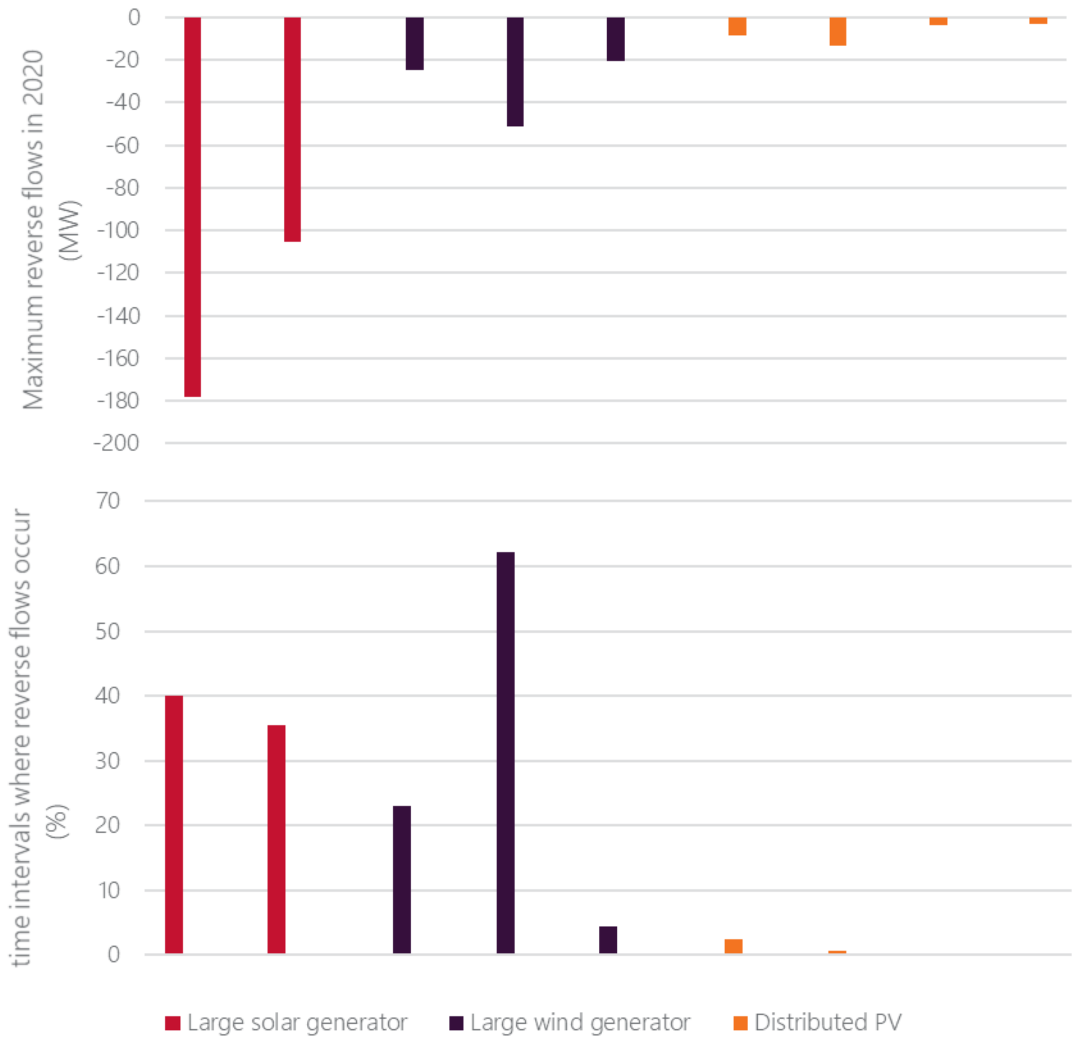
Figure 12 shows a selection of sub-transmission loops that were identified to show reverse flows at significant levels, and on regular occasions. When UFLS circuits are in reverse flows, the triggering of UFLS relays will result in a net trip of generation, rather than load, and will act to exacerbate 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.

On one sub-transmission loop, reverse flows were identified in some periods exceeding 170 MW, and occurring around 40% of the time. This is thought to be associated with the operation of large solar farms connected to this sub-transmission loop. AEMO has confirmed with the NSPs involved that the operation of UFLS relays associated with this sub-transmission loop will trip these large generating units.

On another sub-transmission loop, reverse flows were identified as high as 50 MW, with reverse flows occurring more than 60% of the time. This is thought to be associated with the operation of large wind farms connected to this sub-transmission loop. The NSPs involved have confirmed that UFLS relays associated with this sub-transmission loop will trip these large generating units.

Some sub-transmission loops are also now showing periods of reverse flows related to the generation of DPV. Some of these sub-transmission loops are showing reverse flows around 5-10 MW in the lowest load periods, and showing reverse flows up to 2.5% of the time.

Figure 12 Sub-transmission loops in reverse power flows



AEMO is seeking advice from NSPs on possible approaches to removing these large wind and solar farms from the UFLS scheme. Tripping large generating units during a severe under-frequency event is undesirable. This is discussed further in Section 4.

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 well 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 is operating without the intended safety nets, placing customers at unacceptable risk.

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 large generating units from UFLS

As discussed in Section 3.5, this analysis has revealed that there are a number of large wind and solar farms connected to sub-transmission loops that are within the UFLS scheme. As a consequence, these sub-transmission loops are often in reverse flows, sometimes at high levels. 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 is seeking advice from NSPs on possible avenues for removing these large generating units from the UFLS scheme. This advice should include an assessment of technical and economic feasibility, and any potential implementation opportunities or barriers. Possible options could include, for example:

- Removing the affected sub-transmission loops from the UFLS scheme, and replacing them with loads at other locations.
- Dynamically arming UFLS relays, so that they automatically disarm when the circuit is in reverse flows.
- Moving UFLS relays to a lower voltage level (within sub-transmission loops), so that loads on the loop are tripped by UFLS relays, but the large-scale generation remains connected.
- Or any combination of the above approaches, to be considered on a case by case basis.

AEMO is aware that dynamic arming of UFLS relays could be complex to implement for the sub-transmission loops arrangement in Victoria, since determining whether the whole loop is a net load or net generator requires combining measurements of flows at both ends of the loop. Dynamic arming may therefore require communication between relays at different locations to determine the net load on the loop in real time.

In addition to considering the remediation of existing sites where large 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 advice on how this could be managed.

4.2 Actively monitor UFLS load

As noted in Section 3.2, the amount of total load on the Victorian UFLS is reducing, and in the coming years will reduce to well below the indicative levels suggested by the NER (taken as a percentage of total underlying demand).

So that this can be actively monitored, it may be beneficial to establish a real-time SCADA feed of total net UFLS load in Victoria. This could facilitate monitoring of available UFLS load in real time by both AEMO and the NSPs, and could facilitate active management strategies in periods where net 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. Similar approaches may become warranted in Victoria.

AEMO is seeking advice from NSPs on the options, technical and economic feasibility, and any barriers or opportunities for implementing real-time monitoring of the UFLS load in Victoria.

4.3 Address DPV impacts

As discussed in Section 3.5, there are now some sub-transmission loops in the UFLS that are demonstrating low levels of load and reverse flows at certain times related to high levels of DPV generation.

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:

- 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 sub-transmission loops 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.
  - As part of this process, it may be useful to consider whether it would be beneficial to move UFLS relays to a lower voltage level, so that dynamic arming can be implemented in a more granular manner (tripping some circuits that remain net loads, while others are disarmed). This will need to be explored based on costs and benefits on a case-by-case basis at each UFLS circuit, and will only be suitable at sites where DPV installations are not uniform.
- Consider approaches to management of sub-transmission loops that may have minimal net load at times of high DPV generation, and possible approaches to limit unnecessary disconnection of customers where disconnection of the feeder does not provide much benefit to arrest a frequency decline.

In the longer term, as DPV levels continue to grow it may be necessary to explore highly 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. In particular, voltage rise following disconnection of load (while distributed PV remains operating) may need careful consideration. These longer term options may have long lead times for implementation, and therefore need to be considered early.

It is noted that Market Customers who have expected peak demands in excess of 10MW must provide automatic interruptible load, in accordance with emergency frequency control scheme settings schedules. This applies to battery energy storage systems, when operating as a load. This may partially contribute to a feasible solution.

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 and economic feasibility, any other relevant implementation barriers or opportunities.

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.

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
TUoS	Transmission use of system
UFLS	Under Frequency Load Shedding