Victoria: UFLS load assessment update

May 2023

Analysis of under frequency load shedding data

A report for the National Electricity Market

AEMO

Important notice

Purpose

This report provides information on load levels in the Under Frequency Load Shedding (UFLS) scheme in Victoria. This is related to AEMO's responsibilities under the National Electricity Rules (NER) to assess the adequacy of UFLS (NER 4.3.1(k)).

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Executive summary

In 2021, AEMO provided network service providers (NSPs) with advice on declining under frequency load shedding (UFLS) load levels in Victoria during 2018, 2019 and 2020, related to increasing levels of distributed photovoltaics (DPV)[1].

This report provides a further update on continuing evolution of UFLS load levels in Victoria during 2021 and 2022.

The key findings on UFLS load levels are:

- Annual minimum total net load in the Victorian UFLS scheme has decreased from close to 2 gigawatts (GW) in 2018 to 1.2 GW in 2022.
- This trend is projected to continue as the installation of DPV continues, with minimum total UFLS load in Victoria projected to reach close to 870 megawatts (MW) by late 2025, and 576 MW by late 2026 (based on the 2022 *Integrated System Plan* (ISP) *Step Change* scenario forecast growth in DPV and change in underlying demand).
- Net UFLS load in Victoria has decreased from a minimum of 45% of underlying demand in 2018, to a minimum of 26% of underlying demand in 2022.

The continued growth in DPV is also leading to an increase in UFLS sub-transmission loops experiencing reverse power flows. Reverse power flows are detrimental for UFLS operation because they offset the intended outcome of UFLS activation (disconnecting circuits that are net generators, rather than net loads), and mean that more customers must be disconnected to achieve the same arrest in a frequency decline.

The key findings on reverse power flows are:

- Five sub-transmission loops are identified to have large wind and solar generators located on UFLS circuits (such that they will be disconnected when UFLS relays operate). This is detrimental to UFLS functionality. These loops are in reverse flow up to 60% of the time, and experience reverse power flows as high as 115 MW.
- Sub-transmission loops were also identified with high levels of DPV. In 2022, these loops were in reverse flow for up to 15% of the year, with reverse power flows as high as 42 MW on an individual loop.
- 26 sub-transmission loops on the UFLS scheme that had no reverse power flows in 2018 exhibited reverse power flows in 2022.

Figure 1 shows the percentage of the year that various (anonymised) sub-transmission loops in Victoria are now in reverse flow, and Figure 2 shows the maximum reverse power flow from these sub-transmission loops.

[1] AEMO (August 2021) Phase 1 UFLS Review: Victoria, Analysis of Under Frequency Load Shedding Data, https://aemo.com.au/-/media/files/initiatives/der/2021/vic-ufls-data-report-public-aug-21.pdf?la=en&hash=A72B6FA88C57C37998D232711BA4A2EE.

Figure 1 Percentage of time in reverse flow for anonymised sub-transmission loops in the Victorian UFLS scheme

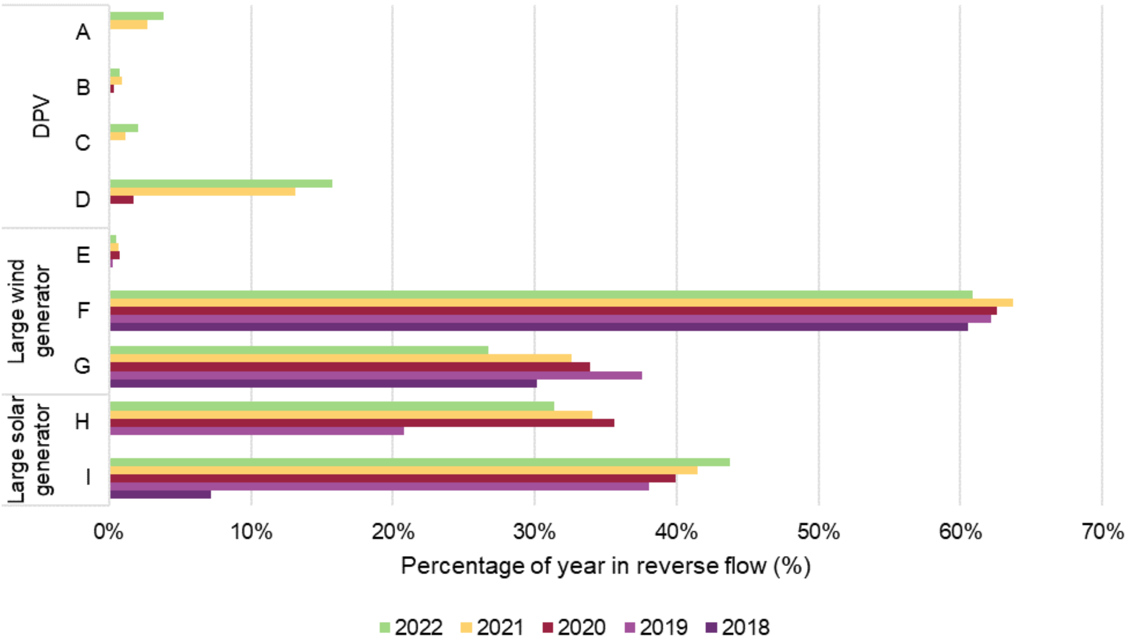
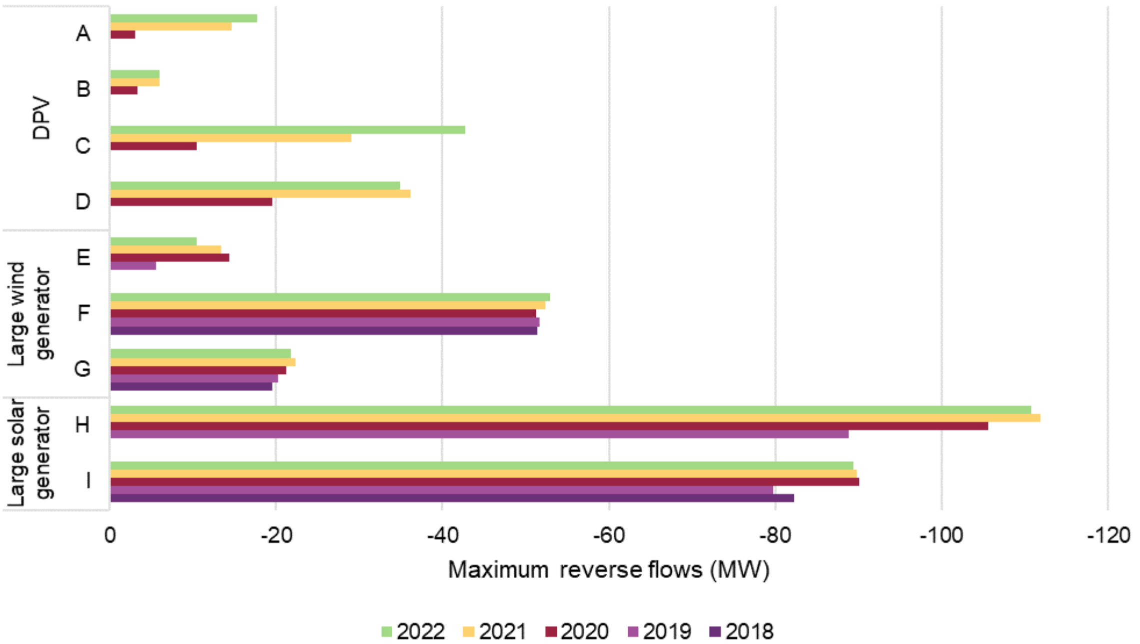


Figure 2 Maximum reverse power flows from anonymised sub-transmission loops in the Victorian UFLS scheme



Recommendations

AEMO is conducting analysis to determine the amount of Emergency Under Frequency Response (EUFR) required in low demand periods. This work program aims to develop clear advice to NSPs on the amount of UFLS load (and other sources of EUFR) that provides adequate response to plausible non-credible contingency events that can occur in these types of periods.

While this analysis progresses, AEMO recommends that Victorian NSPs progress a range of actions, which are detailed in this report.

In summary, AEMO recommends that Victorian NSPs:

- Remove large generating units from the UFLS scheme.
- Update generator connection processes to prevent further large generating units from being connected behind UFLS relays in future.
- Explore implementation of systems to facilitate monitoring of UFLS load in real time (such as a SCADA feed).
- Explore options to address the impacts of DPV on the UFLS scheme.

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1 Background

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 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.

Impacts of distributed photovoltaics

Distributed photovoltaics (DPV) reduces the net load on UFLS circuits, which reduces the ability of the scheme to arrest an under frequency disturbance.

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.

Purpose of this report

Under the National Electricity Rules (NER), AEMO has a number of power system security responsibilities that involve assessing the availability and adequacy of EFCS, 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 (NER 4.3.1(k)).

This report aims to share findings from a load assessment with network service providers (NSPs), who have responsibilities to ensure that sufficient load is under the control of under frequency relays (NER S5.1.10.1).

2 Approach

The approach to data collection and analysis for this report is identical to that applied in AEMO's original advice[2].

In Victoria, most UFLS relays are located at the 66 kilovolts (kV) 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's transmission business (AusNet Transmission) provided a mapping to AEMO indicating which TUoS National Metering Identifier (NMI) was associated with each sub-transmission loop. These sub-transmission loops could 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 2021 and 2022 from sub-transmission (66 kV) TUoS metering, and sum this to determine the total amount of load at each trip setting, in each historical half-hour.

Since the original advice, AEMO and AusNet Transmission have conducted a detailed audit of the UFLS scheme. This has resulted in some small changes to the historical results between the report published in 2021 and this report.

Forward projections are also provided in this report, based on the growth in DPV and underlying load projected in the AEMO 2022 *Integrated System Plan* (ISP), in the *Step Change* scenario. The installed capacity of DPV on each sub-transmission loop was scaled up in each year, based on the regional growth rate.

[2] AEMO (August 2021), Phase 1 UFLS Review: Victoria, https://aemo.com.au/-/media/files/initiatives/der/2021/vic-ufls-data-report-public-aug-21.pdf.

3 Load assessment update

3.1 Net load in UFLS

Figure 3 shows the total net (measured) load in the Victorian UFLS scheme in calendar years 2018 to 2022. Indicative future projections for 2023 to 2026 are also shown in dashed lines.

In historical years, total Victorian UFLS load has reached a maximum of 5,855 megawatts (MW) and minimum of 1,184 MW, and for 90% of the time is within the range 2,000-4,000 MW.

Figure 3 shows that net UFLS load in Victoria has been decreasing over the past few years, particularly in the lowest 20% of the periods, and this trend is projected to continue as levels of DPV continue to increase.

Figure 3 UFLS load: historical and projected (MW)

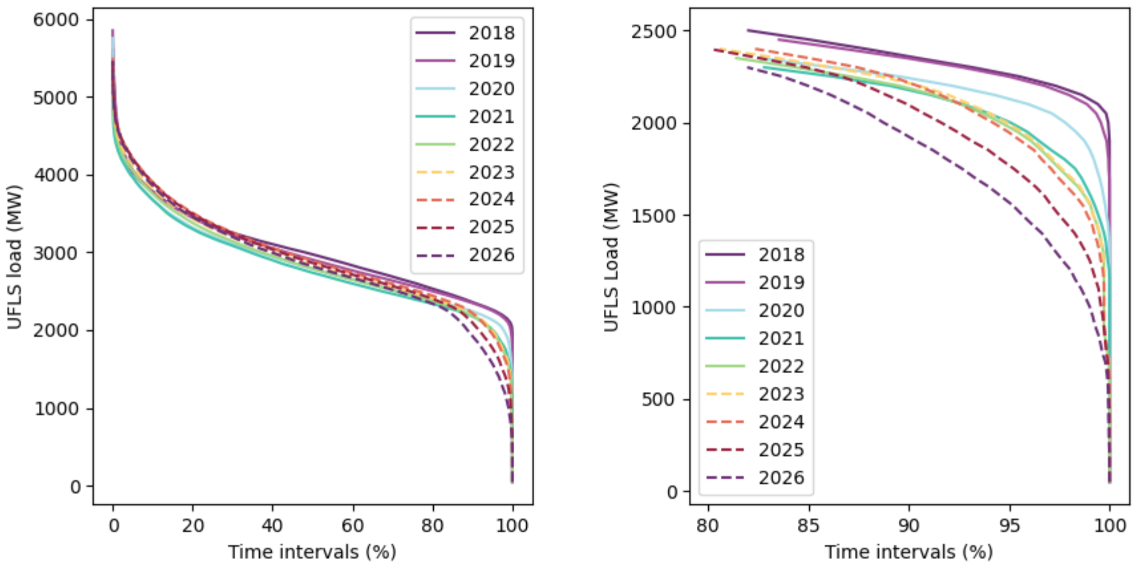
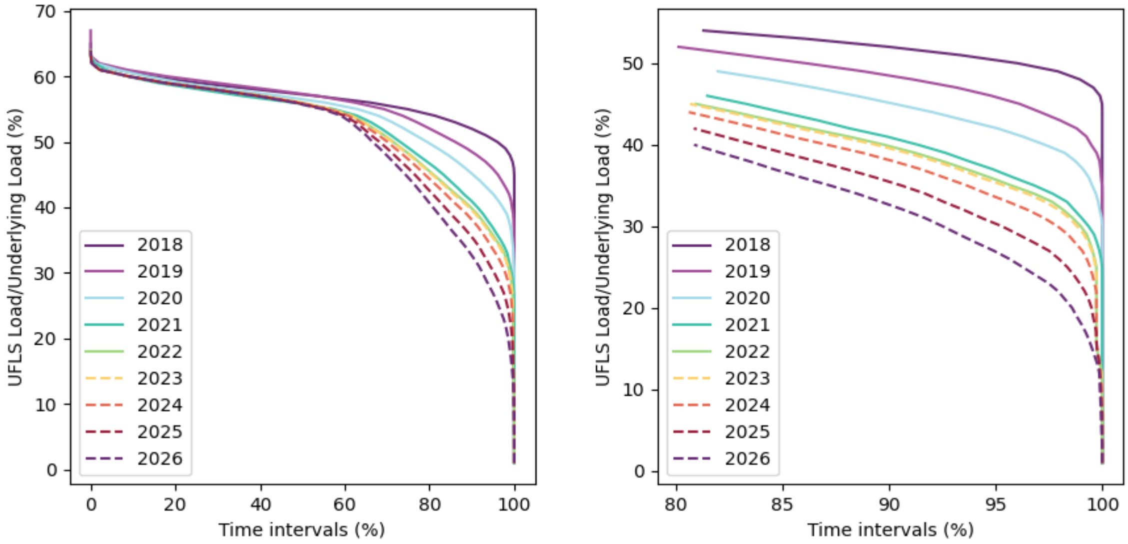


Figure 4 shows UFLS load as a proportion of total underlying load[3] in calendar years 2018 to 2022, and with projections for 2023 to 2026.

This graph shows that for approximately 60% of the time, net UFLS load remains over 50% of underlying load. This corresponds to night-time periods where DPV is not generating. For the remaining periods of the year, DPV generation is reducing the amount of UFLS available.

[3] Underlying load is defined as total Victorian operational demand plus all distributed energy resources (DER) generation.

Figure 4 UFLS load: historical and projected (% of underlying load)

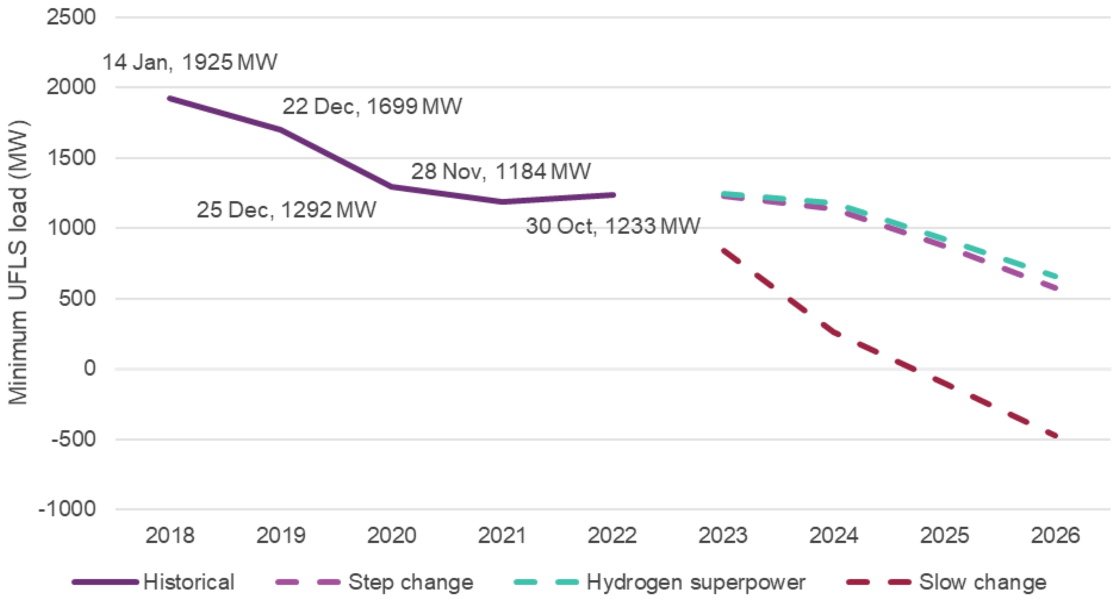


Due to some known increases in industrial load, the amount of UFLS load in 2023 is projected to be similar to levels in 2022. However, based on ISP projections, increases in DPV are projected to outpace increases in underlying load from 2023, with UFLS net load projected to reduce.

3.1.1 Minimum load periods

Figure 5 shows the minimum net UFLS load measured in the Victorian UFLS scheme from 2018, with projections to 2026.

Figure 5 Minimum UFLS levels for historical levels 2018-2022 and projected levels 2023-2026



The annual minimum UFLS load has decreased from 1,925 MW in 2018 to 1,233 MW in 2022. Minimum UFLS load is projected to reach 1,141 MW by late 2024, and 576 MW by late 2026 under the 2022 ISP *Step Change* scenario.

Under the ISP *Slow Change* scenario, where underlying demand growth is lower than in *Step Change*, the amount of UFLS available in the lowest load periods could reach 0 MW by 2025 and the entire Victorian UFLS scheme is projected to be in net reverse flow of -500 MW by 2026.

Underlying load growth in 2022

As shown in Figure 5 above, the minimum ULFS load increased slightly from 2021 to 2022. This is due to a large industrial customer on the UFLS scheme increasing their load by ~100 MW during the 2022 calendar year. This increase in load is concentrated in two UFLS load blocks at the higher frequency bands, which are already quite large.

Frequency studies indicate that Victoria can shed ~10% more load (as a proportion of operational demand in the region) compared with other National Electricity Market (NEM) regions in smaller contingency events. For example, in contingency events studied, Queensland, South Australia and New South Wales tripped approximately 26-33% of regional load, while Victoria tripped around 34-37% of regional load.

This over-shedding in Victoria is related to misalignment of the cumulative load shedding profiles in Victoria versus other regions (with Victoria having proportionally more load in higher frequency bands, compared with other regions). Unequal distribution of UFLS load shed in a continency event can result in outcomes that are problematic for power system security, such as swings on interconnector flows. Excessive load in upper load blocks can also exacerbate risks of frequency overshoot. AEMO has noted these factors for review in more detailed frequency studies.

3.1.2 Summary

Table 1 provides a summary of key data, including the minimum net UFLS load as a percentage of the total underlying load in Victoria. This minimum percentage has declined from 45% in 2018 to 26% in 2022 and is projected to decline further to just 11% by 2026.

A new sub-transmission loop is being added to the scheme by AusNet Transmission in mid-2024 and has been included in the projected UFLS levels post 2024.

Table 1 Net UFLS load summary

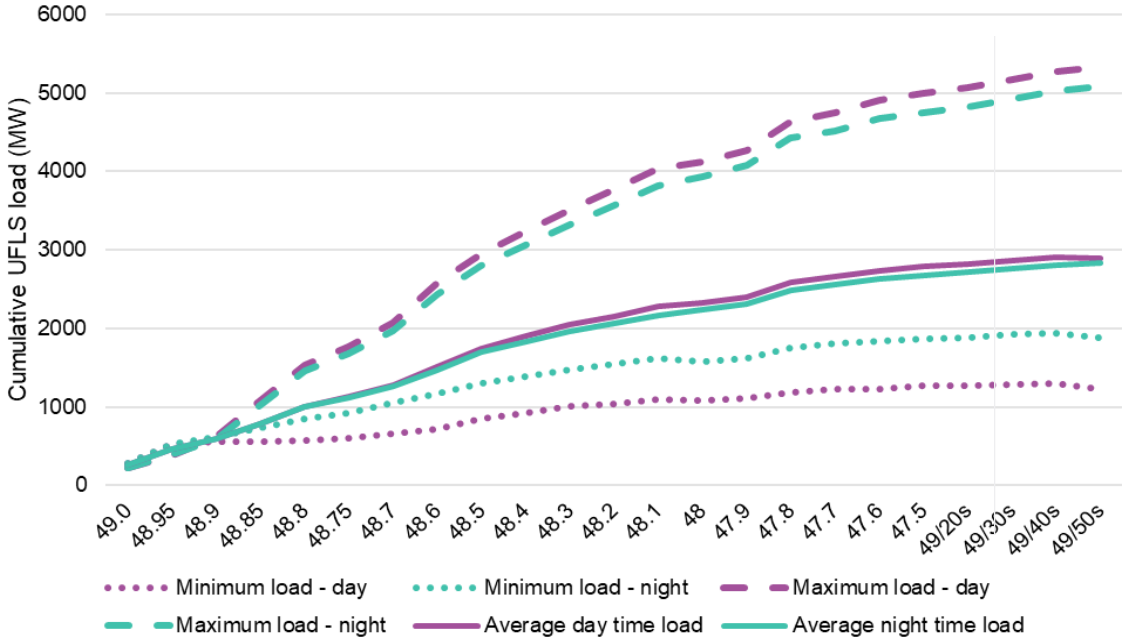
	Historical					Projected (based on ISP *Step Change* scenario)			
	2018	2019	2020	2021	2022	2023	2024	2025	2026
Minimum Operational demand in VIC (MW)	3,484	3,363	2,529	2,333	2,195	2,192	2,017	1,600	1,148
Minimum net UFLS load in VIC (MW)	1,925	1,699	1,262	1,184	1,233	1,230	1,141	870	576
Minimum net UFLS load (minimum % of total underlying load)	45%	35%	30%	26%	26%	25%	22%	17%	11%

3.2 Cumulative net load profile

Figure 6 shows the cumulative net load in the Victorian UFLS, illustrating the spread of load across the various frequency trip settings. The frequency (hertz (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. The figure shows the cumulative UFLS load profile for some example time periods:

- The minimum, average, and maximum net UFLS load measured in day time periods (purple).
- The minimum, average, and maximum net UFLS load measured in night time periods (teal).

Figure 6 Cumulative net UFLS load in 2022



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.

4 Reverse flows

Figure 7 and Figure 8 show a selection of sub-transmission loops that were identified to show significant reverse flows. 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.

Figure 7 Percentage of time in reverse flow for anonymised sub-transmission loops in the Victorian UFLS scheme

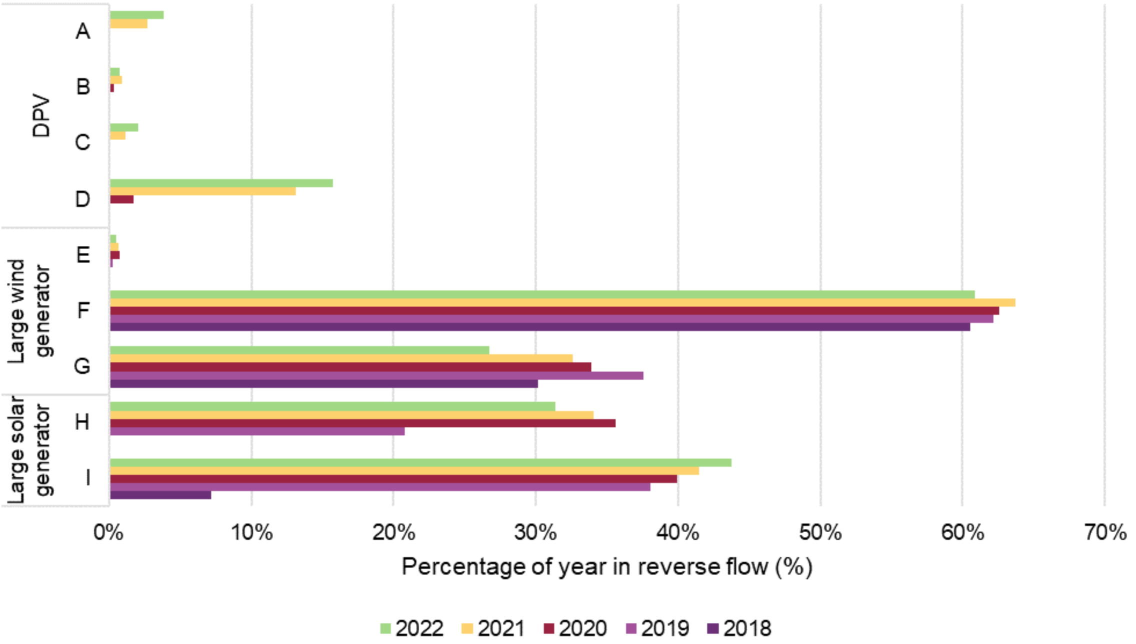
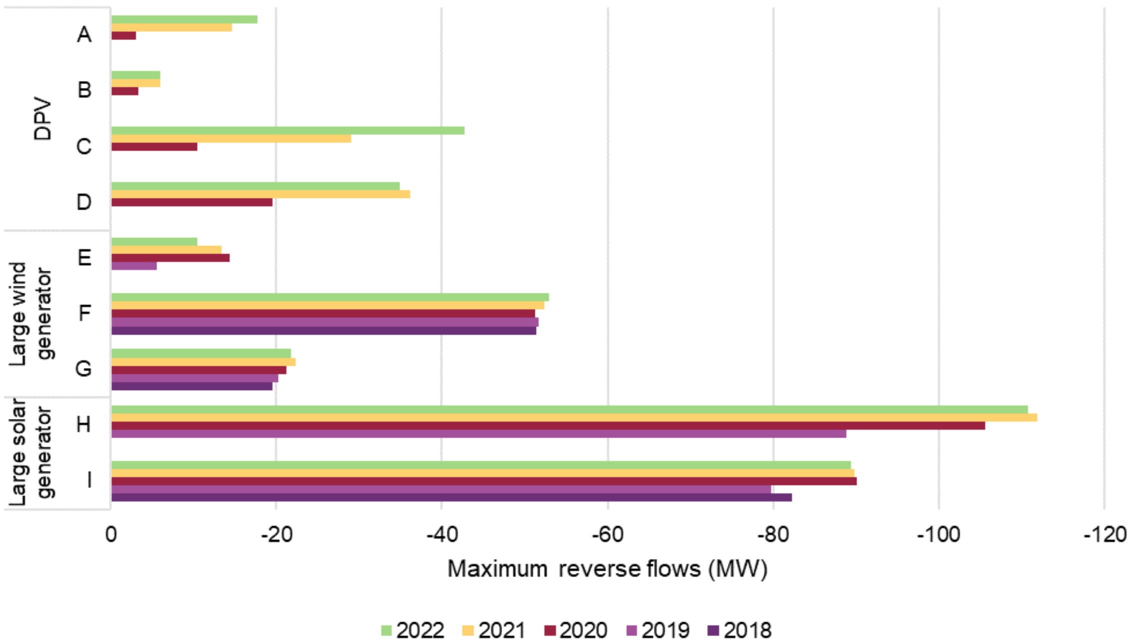


Figure 8 Maximum reverse power flows from anonymised sub-transmission loops in the Victorian UFLS scheme



Reverse flows related to large wind and solar farms

Five sub-transmission loops have been identified that have large wind and solar generators located on the loop, which will be tripped when UFLS activates. These wind and solar farms have a combined capacity of 394 MW. For these loops:

- On one sub-transmission loop, reverse flows were identified in some periods exceeding 112 MW and occurring around 44% of the time.
- 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 issue was identified in AEMO's 2021 advice to NSPs, and they are still in the scheme. It is recommended that the NSPs involved explore 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.

Reverse flows related to DPV

Since AEMO's previous advice to NSPs, the impacts of DPV on reverse flows have escalated significantly; 26 sub-transmission loops on the UFLS scheme that had no reverse power flows in 2018 exhibited reverse power flows in 2022.

In 2022, some of these loops were in reverse flow for up to 15% of the year, with a single sub-transmission loop showing reverse power flows as high as 42 MW.

5 Stage 1 actions estimated benefits

To address the decreasing amount of net load on the UFLS scheme in Victoria, a staged approach for UFLS remediation has been proposed by AEMO, AusNet Transmission, and the Victorian DNSPs, namely:

- **Stage 1 – Add load**: add and remove UFLS sub-transmission loops identified by AusNet Transmission. Loops with large generating units are proposed to be removed from the scheme and alternative loops with large amounts of consistent load are proposed to be included in the scheme.
- **Stage 2 – Reverse flow blocking (66 kV)**: implement reverse flow blocking at selected sites at the 66 kV level. Likely to be feeders with solar or wind farms behind UFLS relay or significant DPV generation that were not removed in Stage 1.
- **Stage 3 – Long-term measures**: explore possible longer-term options. These might include moving UFLS implementation from the 66 kV sub-transmission network to the 22 kV distribution network, or moving UFLS implementation to customer smart meters.

AusNet Transmission has conducted an audit of the Victorian UFLS scheme, and developed a proposal for actions to implement under Stage 1. Based on this detailed proposal, AEMO assessed the amount of load that would be added to the Victorian UFLS scheme. The projected increase in minimum UFLS load from implementation of the proposed Stage 1 actions ranges on average from 340 MW in the ISP *Step Change* scenario to 260 MW in the *Slow Change* scenario. This is shown in Figure 9.

Figure 9 Historical and projected minimum net UFLS load based on existing arrangements and Stage 1 actions

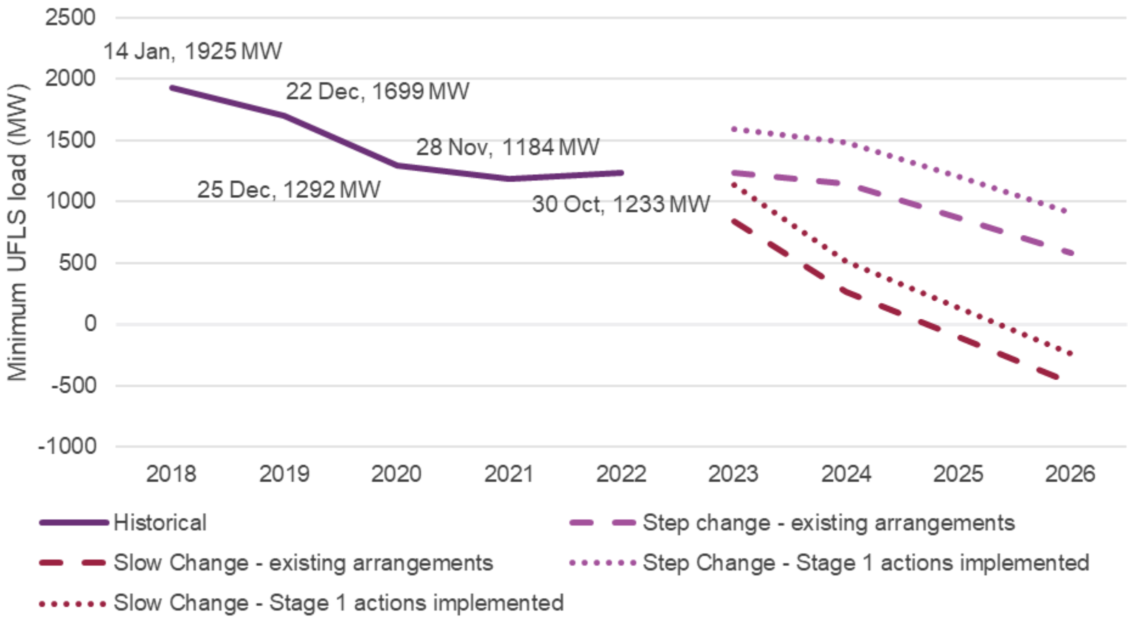
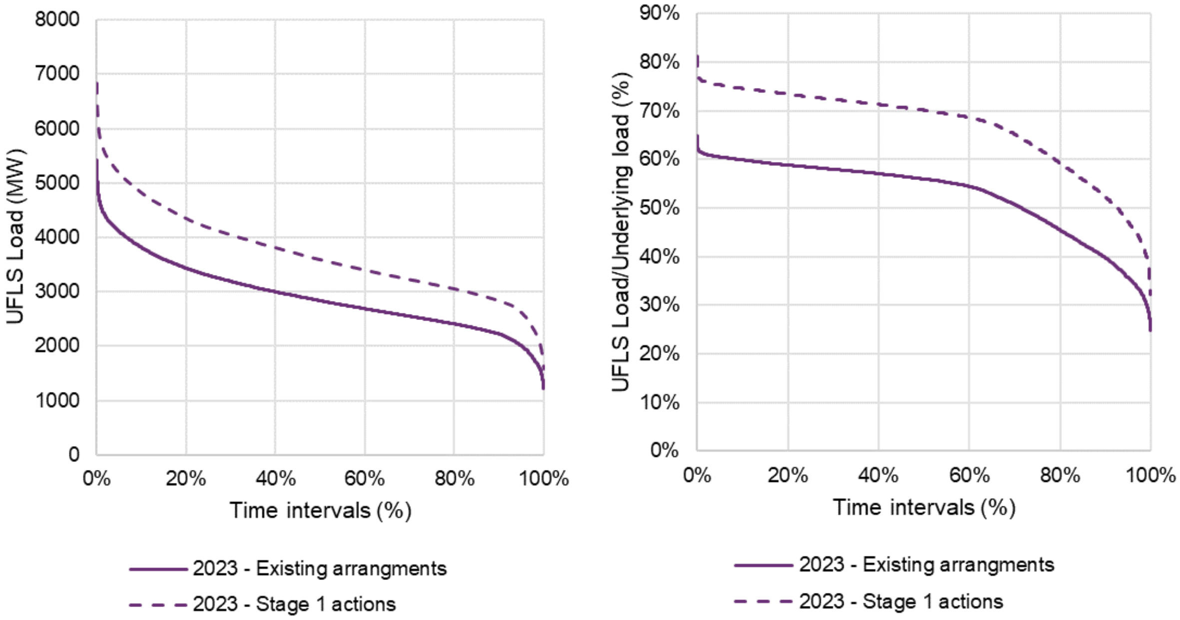


Figure 10 shows a duration curve for total UFLS load in Victoria projected in 2023, based on the ISP *Step Change* scenario. The left panel shows total UFLS load in MW, and the right panel shows UFLS load as a percentage of total underlying load in Victoria.

As shown in Figure 10, Stage 1 actions increase UFLS load across all periods, including periods that already have significant total UFLS load. As discussed in Section 3.1.1, frequency studies indicate that Victoria can shed

~10% more load than other NEM regions in smaller contingency events. Most of the load being added to the scheme in Stage 1 is relatively more sensitive, and therefore is proposed to be added in the lower frequency bands only. This means that these new Stage 1 blocks will trip last, and this effect may not be significantly exacerbated by the proposed implementation of Stage 1 actions. This should be reviewed in future frequency studies to re-balance and optimise the Victorian UFLS scheme.

Figure 10 Total UFLS load based on existing arrangements and Stage 1 actions (2023 forecast, ISP *Step Change* scenario)



6 Recommendations

Based on this updated analysis, AEMO intends to explore the following:

- Review of the Victorian UFLS settings, particularly to explore:
  - Impacts of increased industrial load in the upper bands of the scheme.
  - Impacts of proposed Stage 1 measures.
  - Possible frequency over-shoot.
  - Better aligning unequal distribution of load shed in Victoria versus other NEM regions.
- Analysis to determine the amount of EUFR required in low demand periods. This aims to develop clear advice to NSPs on the amount of UFLS load (and other sources of EUFR) that provides adequate response to plausible non-credible contingency events that can occur in these types of periods. AEMO is targeting delivery of this advice to Victorian NSPs in late 2023.

While this further work is undertaken, AEMO recommends NSPs progress the actions outlined in Table 2.

Table 2 Recommendations for NSPs

Recommendation	Description	Responsible
Remove large generating units from UFLS	As discussed in Section 4, there are several large wind and solar farms connected to sub-transmission loops within the UFLS scheme. This is detrimental to UFLS efficacy, and leads to more customers being shed than is necessary to arrest a frequency decline. It is recommended that these large generating units are removed from the UFLS scheme. Possible options could include: • Moving UFLS relays to a lower voltage level (within sub-transmission loops), so loads on the loop are tripped by UFLS relays, but large-scale generation remains connected. • Dynamically arming UFLS relays, so that they automatically disarm when the circuit is in reverse flows. • Removing the affected sub-transmission loops from the UFLS scheme and replacing them with loads at other locations. 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.	TNSPs – explore options to remediate at 66 kV level DNSPs – explore options that involve distribution network changes
Improve connections processes	It is recommended that NSPs introduce improvements to the connections process for large generating units such that further new connections do not occur behind UFLS relays without suitable rectification. Ideally, Victorian NSPs will agree a consistent approach to handling cost recovery with the connecting parties involved, and the size thresholds where obligations may apply for these connecting parties. This should be negotiated and agreed between NSPs.	DNSPs – develop suitable connections processes, and coordinate with TNSPs
Establish real-time visibility of UFLS load	Establishing a SCADA feed of total net UFLS load in Victoria will allow real-time monitoring of UFLS load by both AEMO and the NSPs and will facilitate a broader range of active management strategies in periods where net UFLS load is low. A real-time SCADA feed of total UFLS load has been established in South Australia and is under development in Queensland. Similar approaches should be explored in Victoria.	TNSPs
Explore options to address DPV impacts	There are now some sub-transmission loops in the UFLS scheme that are demonstrating low levels of load and reverse flows at certain times related to high levels of DPV generation. AEMO recommends that NSPs establish processes to assess the incidence and level of reverse flows occurring at various UFLS circuits.	TNSPs – establish processes to monitor and improve UFLS in

Recommendation	Description	Responsible
	It is also recommended that NSPs explore options for addressing DPV impacts on UFLS. Without ruling out other possibilities, options may include some combination of the following: • Adding further customer load into the UFLS scheme. • 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. • Consider moving UFLS implementation from 66 kV to a lower voltage level (such as 22 kV), so dynamic arming can be implemented in a more granular manner (tripping some circuits that remain net loads, while others are dynamically 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 beneficial at sites where DPV installations are not uniform. This could also provide benefit by facilitating shedding of the most sensitive customers last. • Consider the possible use of smart meter technology to facilitate selective shedding of load at the individual customer level. Trials and careful scheme design will be required. In particular, voltage rise following disconnection of load (while DPV remains operating) may need careful consideration. Disconnection of load may also lead to overload of network assets due to reverse power flow. DNSPs should develop suitable methodologies, models, and processes to investigate these effects. Given the exploratory nature of this work, AEMO recommends that NSPs explore these options now to determine the most appropriate remediation strategies. This will facilitate timely action when AEMO provides advice to NSPs on the amount of EUFR required in Victoria (anticipated in late 2023).	present configuration. DNSPs – explore options for long term remediation