Under Frequency Load Shedding: Exploring dynamic arming options for adapting to distributed PV

October 2023

Victorian case studies

A report for the National Electricity Market

Important notice

Purpose

This report summarises analysis on some possible options for mitigating the decline in net load in Under Frequency Load Shedding (UFLS) schemes in periods with high levels of distributed PV, by implementing dynamic arming (reverse flow blocking) of UFLS relays. It shares early case study analysis for selected sub-transmission loops in the Victorian network, estimating the amount of net load that would be in the UFLS scheme if dynamic arming were implemented at various levels in the network. This aims to inform the areas where Network Service Providers might seek to develop trials or exploratory programs of work to further investigate novel options for maintaining adequate emergency frequency control schemes in their networks.

This publication has been prepared by AEMO using information available at 1 January 2023. Information made available after this date may have been included in this publication where practical.

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Executive summary

Emergency Frequency Control Schemes (EFCS)

If a sudden failure or trip of multiple generating units occurs, power system frequency will rapidly reduce. In the absence of measures to manage such an event, a severe under-frequency event can lead to cascading failure and a black system.

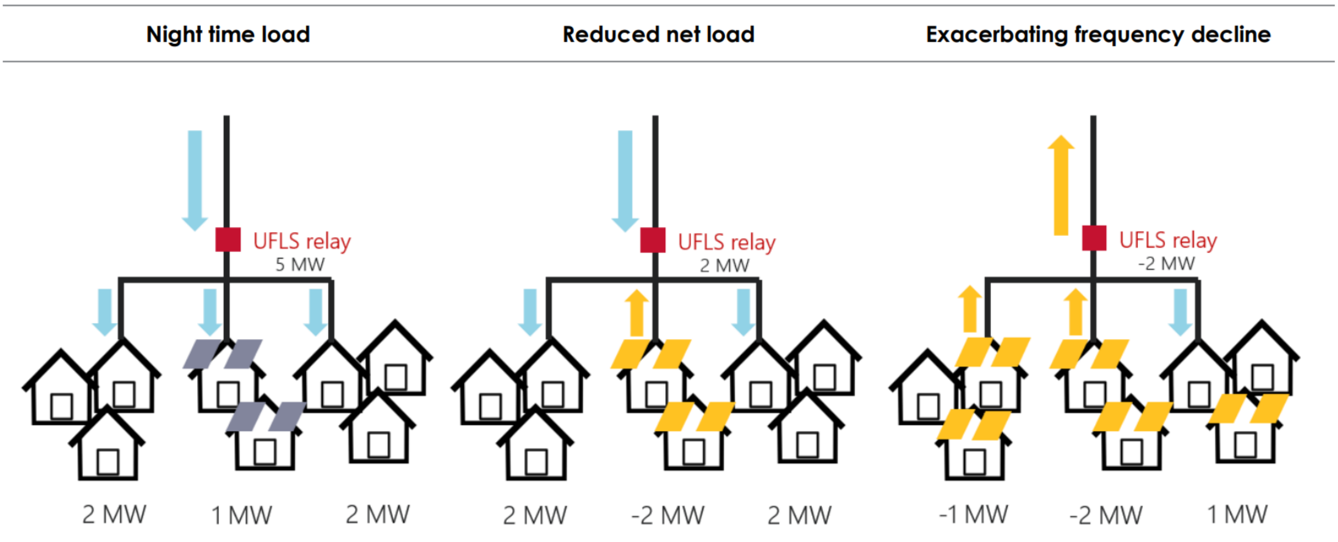
Emergency Frequency Control Schemes (EFCS) are the main measures designed to prevent cascading failure to a black system if a significant multiple contingency event (such as a trip of multiple generating units) occurs. Under Frequency Load Shedding (UFLS) is the main EFCS designed to arrest severe under-frequency events. UFLS involves the automatic disconnection of progressive blocks of customer load in less than half a second.

AEMO has responsibility for coordinating the provision of EFCS by Network Service Providers (NSPs), and determining the settings and intended sequence of response of those schemes (NER 4.3.1(p1)). NSPs have responsibility for ensuring that sufficient load is under the control of under-frequency relays or other facilities (NER S5.1.10.1(a)).

Impact of reverse flows on UFLS

Distributed PV (DPV) is reducing the net load on UFLS circuits, which reduces the effectiveness of this emergency frequency control scheme, as illustrated in Figure 1. If circuits move into reverse flows, a UFLS trip of the circuit acts to exacerbate a frequency decline, rather than helping to correct it. If too many circuits are in large reverse flows, UFLS tripping of circuits in reverse flows could contribute to and exacerbate a cascading failure. Reverse flows in the UFLS scheme also results in unnecessary customer load shedding that does not help to arrest a frequency decline (and will instead exacerbate it).

Figure 1 Reduction in UFLS load from reverse flows



In Victoria, 68 sub-transmission loops were identified as demonstrating reverse flows in some periods in 2022. Five of these sub-transmission loops are associated with large wind and solar generators (showing reverse flows up to 60% of the time and as high as 115MW). A further 26 sub-transmission loops demonstrated reverse flows likely to be associated with DPV, showing reverse flows up to 15% of the year and as high as 42 MW.

AEMO has advised Victorian NSPs on these reverse flows and recommended that Victorian NSPs explore options to address reverse flows in the UFLS scheme[1].

Dynamic arming of UFLS

One option to address reverse flows is to implement "dynamic arming" of UFLS (also termed reverse flow blocking), whereby the UFLS relay monitors the flows on the circuit and disarms the frequency trip setting if the circuit is in reverse flows. This means that the reverse flowing circuits will not be tripped if an under-frequency event occurs, and only those circuits that are net loads (and therefore contribute to arresting the frequency decline) are tripped. Dynamic arming does not restore the original levels of underlying load to the UFLS scheme, but it does prevent the UFLS scheme operating "in reverse" to exacerbate an under-frequency decline (rather than helping to correct it).

UFLS dynamic arming is already being implemented in the South Australian network at present, with rollout progressively through to 2024[2,3]. In South Australia, most UFLS relays are located at 11kV feeders at present. A case-by-case assessment of each UFLS location was conducted to determine the most cost efficient and appropriate option for implementation of dynamic arming. Options considered at each location in South Australia included updating settings of the existing relay to implement reverse flow blocking (where technically possible), replacement of the UFLS relay at the existing location to facilitate implementation of reverse flow blocking (where the existing relay was not capable), or replacing the existing UFLS relays at the transformer level with new relays downstream at the feeder level (where this was cost effective and allowed more selective shedding of feeders that are net loads, while those that are in reverse flows remain connected).

Options for UFLS dynamic arming in the Victorian network

In the Victorian network, UFLS is implemented primarily at the 66kV level at present, shedding whole sub-transmission loops. This report shares some preliminary case studies of selected archetypal sub-transmission loops in Victoria, exploring several options for implementation of dynamic arming of UFLS and assessing how much each would have increased net UFLS load in 2021 in periods with high levels of DPV. The options considered are:

- **Option 1: Dynamic arming at 66kV** – Implement reverse flow blocking (disarming) of UFLS relays at the existing 66kV level – UFLS relays automatically disarm when the circuit moves into reverse flows, preventing reverse operation of the UFLS scheme.
- **Option 2: Dynamic arming at 22kV** – Move UFLS functionality to a lower voltage level (such as 22kV), with reverse flow blocking. This facilitates more granular load shedding (tripping only 22kV circuits that are net loads, while leaving those that are net exporters connected).

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[1] AEMO (May 2023) Victoria: UFLS load assessment update, https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/psfrr/2023-05-25-vic-ufls-2022-review.pdf?la=en&hash=CFDBA2D60117E8E7FE452B2C2F468B3B

[2] AEMO (May 2021) South Australian Under Frequency Load Shedding – Dynamic Arming, https://aemo.com.au/-/media/files/initiatives/der/2021/south-australian-ufls-dynamic-arming.pdf?la=en&hash=C82E09BBF2A112ED014F3436A18D836C

[3] Australian Energy Regulator (7 April 2022), https://www.aer.gov.au/networks-pipelines/determinations-access-arrangements/cost-pass-throughs/sa-power-networks-cost-pass-through-emergency-standards-2021%E2%80%9322

- **Option 3: Dynamic arming at AMI** – Move UFLS functionality to individual customer sites via advanced metering infrastructure (AMI). This facilitates even more granular load shedding, tripping only individual customers that are net loads, while leaving exporting customers connected[4].

These options are intended to provide high level illustrative case studies, rather than an exhaustive consideration of all options. Each network location will have a variety of options that should be assessed individually by NSPs.

Dynamic arming at AMI

Implementing dynamic arming at individual customer sites via AMI is relatively novel, and to AEMO's knowledge has only been utilised in very limited applications internationally to date. It is considered in this report as an early pre-feasibility assessment, in the context of considering whether investment to implement dynamic arming at other network voltage levels (such as 22kV) is appropriate, or whether this investment could perhaps be bypassed in some locations by implementing UFLS dynamic arming at individual customer sites via AMI. If subsequent investigations determine that UFLS can be implemented at AMI with only remote firmware updates to existing infrastructure (no hardware changes required at customer sites) and confirm suitably robust and reliable operation of this function, it is possible that in some cases this could offer a lower cost alternative, and longer term value than implementing UFLS at voltage levels below 66kV (the net load available from implementation of dynamic arming at the network level may become progressively less over time as DPV levels continue to grow). Acknowledging the novel nature of this option, this report aims to explore whether it might be worth exploring further, and to document the various questions and challenges that may need to be explored as part of that process.

Preliminary discussions with meter manufacturers suggest that implementation of UFLS capability at customer AMI is feasible, and initial estimates suggest it could be rolled out in the near-term to approximately 10% of meters installed in Victoria at present without any hardware changes required. In the near term with the present infrastructure available, this would need to be implemented on a whole-site basis with dynamic arming (tripping the whole customer site if it is a net load, or leaving the whole site connected in periods where it is net exporting). In the longer term, if new/replacement meters were installed with UFLS functionality and load/DPV on separate contactors, it could be possible to trip only customer load while leaving on-site generation connected to the grid, providing more net load to support UFLS functionality. This option is not explored in this report, since it could only be implemented if there were hardware changes at the customer sites involved.

Findings

Case studies of four archetypal sub-transmission loops in Victoria were explored, based on data from the 2021 year. The case studies suggest that the optimal options for each sub-transmission loop will likely differ, and should be considered case by case.

Household and small business loops

For the case study loop with a large proportion of household and small business load, it appears that enabling UFLS via AMI that are capable of this functionality at present might offer a similar level of net UFLS load as implementing new UFLS relays at the 22kV level. This suggests that it may be appropriate for NSPs to explore the AMI option further, since it could represent a lower cost alternative in some locations to moving UFLS functionality from 66kV to a lower voltage level (and may also be more robust over the longer term as levels of

[4] With configuration changes, AMI could potentially facilitate tripping the customer load on site, while leaving customer generation connected. This option has not been quantified in this report, but could be considered in future work.

distributed resources continue to grow, although future projections have not been explicitly quantified in this report).

The case study suggests this option could be implemented as a hybrid arrangement, with dynamic arming introduced at the existing 66kV level and delivering normal UFLS functionality in most periods (conventional load shedding at the 66kV level would continue to apply approximately 97% of the time in 2021). The 66kV UFLS relays would be programmed to disarm when net demand on the loop at the 66kV level falls below a non-zero threshold (estimated at approximately 8.5 MW for this case study sub-transmission loop in 2021). For periods with lower demand levels (approximately 3% of the time in 2021, and likely to increase as DPV levels continue to grow), shedding at the 66kV level would be automatically disabled, and dynamic arming at capable AMI sites would instead apply, shedding individual customer sites that are net loads only, if power system frequency falls below the pre-determined thresholds.

Given the novel nature of this option, and the likely long lead times to develop it towards implementation, this case study suggests it may be prudent for DNSPs to consider further exploration of this option as a trial on a selection of sub-transmission loops that have a high proportion of household and small business load. This could allow DNSPs to develop learnings and inform possible longer term options for EFCS adequacy. If successful, such a trial might also inform future review of Victorian AMI minimum meter specifications for new/replacement meters to possibly include UFLS functionality, and/or involve separate contactors for separated shedding of load and generation on site. Such a review would need to consider practical implications and costs for customers from implementing hardware changes at customer sites.

Commercial loops

For the case study loop with a large proportion of commercial load, moving UFLS functionality to the 22kV level appears to be a suitable option in the near term. There are minimal UFLS-capable AMI on commercial loops, so the AMI option is not available with present hardware. Commercial loops can include embedded generators connected at the 22kV level, which can be excluded from UFLS if relays are moved to a lower voltage level.

It may be worthwhile for DNSPs to explore other (non-AMI) alternatives to enable UFLS functionality at individual commercial/industrial customer sites, particularly if these customers are in the process of commissioning on-site generation, or during the commissioning process for new load connections.

Loops with large wind/solar farms

For loops with large generators connected at the 66kV level, moving UFLS functionality to the 22kV level offers a significant and immediate increase in net UFLS load by excluding the large wind and solar generators from tripping via UFLS. This case study suggests this may be a suitable option for these loops in the near term.

For loops that also have a high proportion of household and small business load, the amount of net load available at the 22kV level may deteriorate over time as DPV levels continue to increase, and the value of exploring AMI UFLS options may improve over time.

Ongoing next steps

AEMO is working on assessing the adequacy of EFCS to arrest plausible multiple contingency events that could occur in periods with low demand and high generation from DPV. This ongoing analysis aims to account for the evolution of the power system in many dimensions, such as:

- including the effects of large battery energy storage systems (BESS) and other inverter based resources (IBR) which provide fast frequency response and help to arrest a rapid frequency decline,
- the complex interactions and dynamics of DPV and load tripping behaviours during UFLS tripping timeframes,
- changing dispatch patterns and interconnector flows which will lead to changes in the size of plausible multiple contingency events that could occur, and
- accounting for new risks, such as cybersecurity.

As this analysis progresses, AEMO intends to provide further advice to NSPs on the adequacy of EFCS to inform further work NSPs may need to undertake to maintain adequate EFCS functionality.

In parallel, AEMO has informed NSPs on the declining levels of UFLS load[5,6], which is likely to affect UFLS functionality. AEMO recommends that NSPs proactively consider options for improving EFCS functionality, so that any remediation required can be progressed in a timely manner on receiving AEMO's advice. The analysis presented in this report suggests that some cost-effective options might be relatively novel, and will require trials and extensive investigation prior to wide-spread implementation and investment. This highlights the importance of NSPs proactively initiating early investigative work. NSPs will need to investigate suitable funding pathways for resourcing this work.

These early case studies suggest it would be prudent for Victorian NSPs to further investigate the areas outlined in Table 1.

Table 1 Recommended areas for further investigation by Victorian NSPs

Topic	Details
Sub-transmission loops with large wind/solar farms	Explore options for addressing reverse flows on sub-transmission loops with large wind/solar farms behind UFLS relays.
Generator connection processes	Update generator connection processes to consider and address impacts on UFLS, aiming to ensure future large generating units are not connected behind UFLS relays.
AMI UFLS feasibility	Explore the many outstanding questions to assess feasibility of UFLS via AMI. This includes: • Clarifying costs and rollout pathways, and the proportion of capable AMI in the network. • Confirming the UFLS tripping functionality available in AMI is adequately fast (~200ms) and adequately robust, and will not lead to excessive maloperation. • Confirm or develop suitable communication systems with AMI to manage UFLS functionality in real-time, including restoring customers in a timely manner. • Developing an understanding of the possible implications for the low voltage network from tripping a large proportion of customer load via AMI, while leaving DPV generating. In particular, consider possible overload of distribution network elements, and explore the possibility of a transient high voltage spike that could lead to AS/NZS4777.2:2020 compliant inverters disconnecting on passive anti-islanding voltage limits (which could defeat the intention of UFLS via AMI). • Exploring the suitability of the present regulatory framework for AMI, and identify and address any barriers for application of AMI in this manner. • Suitable consumer engagement and development of social license for this approach • Quantifying the robustness of this approach versus other options in future projections, with continuing growth in DPV.
AMI UFLS trial	Consider establishing a trial implementation of UFLS via AMI for existing capable meters on selected sub-transmission loops, to develop learnings and inform possible future options.

[5] 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?la=en&hash=A72B6FA88C57C37998D232711BA4A2EE

[6] AEMO (May 2023) Victoria: UFLS load assessment update, https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/psfrr/2023-05-25-vic-ufls-2022-review.pdf?la=en&hash=CFDBA2D60117E8E7FE452B2C2F468B3B

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Emergency Frequency Control Schemes (EFCS)

If a sudden failure or trip of multiple generating units occurs, power system frequency will rapidly fall. In the absence of measures to manage such an event, a severe under-frequency event can lead to cascading failure and a black system.

Emergency Frequency Control Schemes (EFCS) are the main measures designed to prevent cascading failure to a black system if a significant multiple contingency event occurs. They are the last resort “safety net” designed to arrest power system frequency decline in a severe under-frequency event (typically caused by a sudden large deficit of generation in the power system).

AEMO has responsibility for coordinating the provision of EFCS by Network Service Providers (NSPs), and determining the settings and intended sequence of response of those schemes (NER 4.3.1(p1)). NSPs have responsibility for ensuring that sufficient load is under the control of under-frequency relays or other facilities (NER S5.1.10.1(a)).

Under Frequency Load Shedding

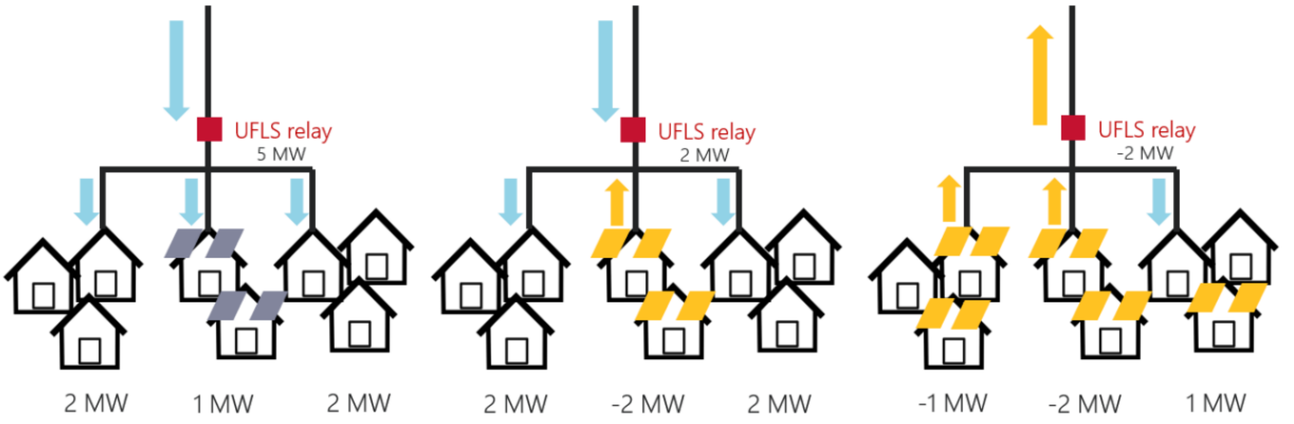
Under Frequency Load Shedding (UFLS) is the main type of EFCS used to manage under-frequency events. UFLS involves relays in the network which locally detect the under-frequency condition, and autonomously open circuit breakers to disconnect blocks of customer load, within less than half a second. This aims to rapidly correct a severe supply-demand imbalance in the power system, arresting the frequency decline.

Impacts of distributed PV on UFLS

As illustrated in Figure 2, distributed PV (DPV) is reducing the net load on distribution feeders. This reduces the net load in the UFLS scheme, which reduces the effectiveness of the scheme in arresting a frequency decline. With high levels of DPV generation, circuits can move into reverse flows, and the action of UFLS relays to disconnect circuits will then act to exacerbate an under-frequency disturbance, rather than helping to correct it.

Figure 2 Net load available on UFLS is reducing as distributed PV levels increase

Night time load	Reduced net load	Exacerbating frequency decline



Purpose of this report

In 2021, AEMO advised Network Service Providers (NSPs) in South Australia[7], Victoria[8], Queensland[9], and New South Wales[10] that net load in the UFLS scheme is reducing and recommended that they explore options for rectification. Since that time, AEMO and the NSPs have been exploring a range of options for remediation of UFLS schemes, especially in periods with high levels of DPV generation. A further update on UFLS load levels in Victoria was published in May 2023[11].

This report shares some preliminary case studies of selected archetypal sub-transmission loops in Victoria, with the aim of beginning to explore the feasibility of some of these options for increasing the net load available for UFLS, particularly in the context of growing levels of DPV. This aims to inform the areas where NSPs might seek to develop trials or exploratory programs of work to further investigate novel options for maintaining adequate emergency frequency control schemes in their networks.

AEMO's ongoing work on UFLS adequacy

AEMO is working on assessing the adequacy of EFCS to arrest plausible multiple contingency events that could occur in periods with low demand and high generation from DPV. This ongoing analysis accounts for the evolution of the power system in many dimensions, such as including the effects of large battery energy storage systems (BESS) and other inverter based resources (IBR) which provide fast frequency response and help to arrest a rapid frequency decline, the complex interactions and dynamics of DPV and load tripping behaviours

[7] 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&hash=A57E8CA017BA90B05DDD5BBBB86D19CD

[8] 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?la=en&hash=A72B6FA88C57C37998D232711BA4A2EE

[9] AEMO (December 2021) Phase 1 UFLS Review: Queensland, https://aemo.com.au/-/media/files/initiatives/der/2022/queensland-ufls-scheme.pdf?la=en&hash=A451A3AEA814BFBB16CE0AAD185CB7FE

[10] AEMO (December 2021) Phase 1 UFLS Review, New South Wales, https://aemo.com.au/-/media/files/initiatives/der/2022/new-south-wales-ufls-scheme.pdf?la=en&hash=D8E106C09B66F9EAC4C6601E068784F0

[11] AEMO (May 2023) Victoria: UFLS load assessment update, https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/psfrr/2023-05-25-vic-ufls-2022-review.pdf?la=en&hash=CFDBA2D60117E8E7FE452B2C2F468B3B

during timeframes of UFLS tripping, changing dispatch patterns and interconnector flows which will lead to changes in the size of plausible multiple contingency events that could occur, and accounting for new risks, such as cybersecurity. As this analysis progresses, AEMO intends to provide further advice to NSPs on the adequacy of EFCS and further work NSPs may need to undertake to maintain adequate EFCS functionality.

UFLS in Victoria

In Victoria, UFLS relays and circuit breakers are mainly located at the 66kV sub-transmission level and disconnect whole “sub-transmission loops”[12]. In periods that are unaffected by DPV, individual sub-transmission loops typically have load in the range of 4-36 MW and in some cases, load can be as high as 250 MW on an individual loop.

Because UFLS is implemented at the 66kV level in Victoria, in some cases there have been large (~30-100 MW) generating units connected on 66kV sub-transmission loops that will be disconnected when UFLS activates. This is detrimental to UFLS functionality. AEMO has identified five sub-transmission loops with large wind and solar farms connected that demonstrate reverse flows up to 60% of the time, and as high as 115 MW.

In periods unaffected by DPV, the total net load on the UFLS scheme in Victoria is typically in the range of 2-4GW, constituting around 50-60% of underlying load in the region. Due to the impacts of DPV, total net load in the Victorian UFLS has now reached a minimum of 1,184 MW (occurring on 28 November 2021), equivalent to 26% of underlying load at the time. Minimum net total load in the Victorian UFLS scheme is projected to continue to fall to a minimum total of ~600 MW and 11% of underlying load by 2026[13].

There is also considerable evidence of UFLS circuits in reverse flows related to DPV. 26 sub-transmission loops in the UFLS scheme that had no reverse power flows in 2018 were identified as demonstrating reverse flows in some periods in 2022. These are thought to be primarily related to growth in DPV. Some of these were in reverse flows for up to 15% of the year, with individual sub-transmission loops showing reverse flows as high as 42 MW.

[12] In other NEM regions, UFLS relays and circuit breakers are more typically located at lower voltage levels, in the 22kV or 11kV network.

[13] Based on DPV growth and underlying demand growth projected in the AEMO 2022 Integrated System Plan, Step Change scenario.

2 Options for consideration

AEMO has collaborated with the Victorian NSPs to identify some possible options for increasing the net UFLS load and improving emergency under-frequency response in Victoria.

Stage 1 rectification proposal

AusNet Transmission conducted an audit of the Victorian UFLS and identified several sub-transmission loops with low levels of DPV that could be added to the scheme. They also identified several UFLS loops that are in the UFLS scheme at present but are in frequent reverse flows, and therefore have proposed these could be removed from the scheme to increase UFLS net load. AusNet Transmission has developed a proposal for this "Stage 1" UFLS remediation work and is progressing through approvals for implementation.

This "Stage 1" work is anticipated to increase net load in minimum load periods by approximately 400 MW and provide a short-term improvement in UFLS performance in low load periods. However, even with these Stage 1 works implemented, minimum net total load in the Victorian UFLS scheme is projected to continue to fall to a minimum total of ~910 MW and 18% of underlying load by 2026[14].

Impact of fast frequency response (FFR) on EFCS adequacy

Inverter based resources, such as battery energy storage systems (BESS) can deliver a fast frequency response (FFR) which helps to arrest the rapid frequency decline following a multiple contingency event. This means that new BESS connecting to the network can help contribute emergency under frequency response to support the adequacy of EFCS for managing multiple contingency events. AEMO is including the FFR delivered by BESS and other types of inverter based resources in the ongoing assessment of EFCS adequacy.

Dynamic arming of UFLS

One option to address the impacts of reverse flows on UFLS is to implement "dynamic arming" of UFLS (also termed reverse flow blocking), whereby the UFLS relay monitors the flows on the circuit, and disarms the frequency trip setting if the circuit is in reverse flows. This means that the reverse flowing circuits will not be tripped if an under-frequency event occurs, and only those circuits that are net loads (and therefore contribute to arresting the frequency decline) are tripped. Dynamic arming does not restore the original levels of underlying load to the UFLS scheme, but it does prevent the UFLS scheme operating "in reverse" to exacerbate an under-frequency decline (rather than helping to correct it).

UFLS dynamic arming is already being implemented in the South Australian network at present, with rollout progressively through to 2024[15,16]. In South Australia, most UFLS relays are located at 11kV feeders at present. A case-by-case assessment of each UFLS location was conducted to determine the most cost efficient and appropriate option for implementation of dynamic arming. Options considered at each location in South Australia included updating settings of the existing relay to implement reverse flow blocking (where technically possible), replacement of the UFLS relay at the existing location to facilitate implementation of reverse flow blocking (where

[14] Based on DPV growth and underlying demand growth projected in the AEMO 2022 Integrated System Plan, Step Change scenario.

[15] AEMO (May 2021) South Australian Under Frequency Load Shedding – Dynamic Arming, https://aemo.com.au/-/media/files/initiatives/der/2021/south-australian-ufls-dynamic-arming.pdf?la=en&hash=C82E09BBF2A112ED014F3436A18D836C

[16] Australian Energy Regulator (7 April 2022), https://www.aer.gov.au/networks-pipelines/determinations-access-arrangements/cost-pass-throughs/sa-power-networks-cost-pass-through-emergency-standards-2021%E2%80%9322

the existing relay was not capable), or replacing the existing UFLS relays at the transformer level with new relays downstream at the feeder level (where this was cost effective and allowed more selective shedding of feeders that are net loads, while those that are in reverse flows remain connected).

Options for dynamic arming of UFLS in Victoria

This report explores a number of options for implementing dynamic arming of UFLS in Victoria, summarised in Table 2. The case studies in this report assess the possible increases in UFLS load from implementation of each option on four different case study archetypal sub-transmission loops.

Table 2 Possible options for implementing dynamic arming of UFLS in Victoria

Remediation Action	Description
Option 1 – Dynamic arming at 66 kV	Implement "reverse flow blocking" of UFLS relays at the existing relay location (66kV). This means that UFLS relay activation will be blocked (disarmed) dynamically when the sub-transmission loop is in reverse flows. This prevents the disconnection of the whole loop when the circuit is in reverse flows but maintains the load in the UFLS scheme (unchanged) during overnight periods when the loop is a net load.
Option 2 – Dynamic arming at 22 kV	UFLS relays could be permanently disarmed at the 66 kV terminal stations, and new relays introduced at 22 kV zone substations, with dynamic arming implemented. This would allow selective arming and disarming of UFLS relays at the more granular 22kV level, as each 22kV circuit individually moves into reverse flows. It would also mean that any large-scale generation connected at the 66kV level could be removed from the UFLS (avoiding tripping of these large-scale generators when UFLS activates).
Option 3 – Dynamic arming at AMI	Some customer smart meters can respond to under-frequency events by measuring frequency locally and disconnecting the site if frequency falls below thresholds. This could mean that UFLS functionality could be moved to the individual customer level with minimal additional cost, where appropriate meters with this functionality have been installed, and where DNSPs have appropriate systems in place. The initial implementation could involve dynamic arming at the customer level (tripping whole sites that are net loads, and leaving sites that are net exporters connected and uninterrupted), utilising existing AMI infrastructure without any hardware changes required. With hardware changes, more UFLS load could potentially be accessed if new/replacement meters were installed with UFLS functionality and the customer load and generation on separate control contactors. This could allow disconnection of all customer load on the site while allowing all generation on the site to continue operation uninterrupted. This option is further detailed in section 3.

These options are intended to provide high level illustrative case studies, rather than an exhaustive consideration of all options. Each network location will have a variety of options which should be assessed individually by NSPs (for example, DNSPs could consider dynamic arming at the distribution substation as another alternative).

Implementing dynamic arming at individual customer sites via AMI is relatively novel, and to AEMO's knowledge has only been utilised in very limited applications internationally to date. It is considered in this report as an early pre-feasibility assessment, in the context of considering whether investment to implement dynamic arming at other network voltage levels (such as 22kV) is appropriate, or whether this investment could perhaps be bypassed in some locations by implementing UFLS dynamic arming at individual customer sites via AMI. Implementing UFLS at AMI might offer a lower cost alternative (if it can be implemented with existing hardware), and may offer longer term applicability (implementation of dynamic arming at AMI might offer a more robust option to maintain UFLS load levels over time as DPV levels continue to grow, particularly if future AMI installations can be implemented with DPV and load on separate contactors, allowing separate shedding). Acknowledging the novel nature of this option, this report aims to explore whether it might be worth exploring further, and to document the various questions and challenges that may need to be explored as part of that process.

3 Feasibility of AMI for UFLS

3.1 Desired functionality

If UFLS functionality were implemented via AMI, to increase the load available for UFLS, the desired outcome would be frequency trip settings implemented at each customer site such that the meter autonomously and automatically disconnects net load on the customer site when frequency falls below pre-defined thresholds, within similar timeframes to existing UFLS (e.g. ~200ms), with high reliability, and very low rates of mal-operation. Frequency trip settings would be diversified across the various meters in the region (with settings at each site ranging between 49Hz and 47.5Hz) to produce a progressively larger load disconnection across the region for a deeper frequency disturbance. This aims to replicate the functionality of the existing UFLS scheme, which is outlined in more detail in section A1.2.

3.2 Smart meter technology

Some smart meters currently in use in the Australian market can measure frequency at the customer point of connection to the distribution network and open a control contactor to disconnect the site (or a controlled load on site) based on a local algorithm. This suggests the possibility of performing UFLS functionality at individual customer sites, utilising existing infrastructure.

Looking at the Victorian market for the purposes of this report, there are three possible configurations for UFLS action, depending on the meter setup:

1. **Configuration 1: Controlled load only** – Disconnects the controlled load (usually a hot water load) on the customer site but leaves the rest of the customer's load and generation connected. This could be applied at sites that have the controlled load on a separate controllable meter element or control contactor, where the existing meter features the necessary frequency response capability.
2. **Configuration 2: Whole site** – Disconnects the whole customer site if it is a net load, while allowing sites that are net exporters to continue operation uninterrupted. This could be applied at sites where the existing meter model has the ability to respond to frequency, but the meter configuration is such that the whole site (load + generation) is on a single controllable supply contactor (this is the typical meter configuration at present). Firmware upgrades could allow meters in Configuration 1 (disconnecting the controlled load only) to be changed to Configuration 2 remotely and without hardware upgrades.
3. **Configuration 3: Load and generation separately** – Disconnects the load on customer sites, while allowing the generation at customer sites to continue operation uninterrupted. This would require the load and generation on site to be configured on separate control contactors. This control contactor arrangement is unusual at the moment due to the net metering requirements applied for distributed PV in the NEM at present.

Most installations of UFLS capable AMI in Victoria are in configurations 1 & 2, because the most common form of smart meter is a single channel meter with the controllable contactor either being the controlled load or the supply contactor. Configuration 3 would require hardware changes at most customer sites (to configure DPV and load at the site onto separate meter elements or control contactors), and is likely to require re-wiring or re-configuration of customers' electrical installations. This report has focused on exploring the near-term feasibility of configuration 1 & 2 only.

If further analysis indicates this is worthwhile, an evolution towards configuration 3 could perhaps be implemented progressively as new UFLS capable metering equipment replaces currently installed smart metering at end-of-life. It is understood that most of the AMI installed in Victoria has been installed within the last 15 years and will not near end-of-life replacement for some time (anticipated AMI lifespans are 30 years or more).

3.3 Feasibility

Some early feasibility aspects have been explored as part of this analysis, to determine whether further exploration is justified. Key questions raised are summarised below. Significant further investigation is required to confirm whether this could be implemented to deliver the required functionality.

Can AMI activate fast enough, and avoid spurious tripping?

UFLS is designed to respond to severe under-frequency contingency events, where the Rate of Change of Frequency (RoCoF) can be in the range of 1-3 Hz/s. This means that to successfully arrest frequency decline, a UFLS device response (to measure the frequency decline and activate load tripping) is typically required within ~200ms. For the NEM (operating at 50Hz), each cycle has a duration of 20ms, so UFLS devices need to be able to accurately measure a change in frequency and respond within only 5-10 cycles. This needs to include allowance of a suitable measurement window to prevent spurious tripping in response to distortions in the frequency wave; if the measurement window is too short, common grid disturbances such as voltage dips, oscillations, and phase angle jumps can lead to spurious operation (misreading of frequency leading to spurious disconnection of customers), which needs to be avoided with high reliability. Following UFLS activation, customers typically remain disconnected until AEMO confirms the power system is stable and provides permission to restore to NSPs to begin restoring customer load, so if spurious tripping occurs, customers could remain disconnected for some time until this is manually rectified. This is highly undesirable.

Discussions with two meter manufacturers that have significant market share in Victoria have indicated that there are some AMI products presently available in the Victorian fleet that can perform a rapid (50-150 ms) and sufficiently accurate measurement of frequency, and that this capability is already in use in some international markets to contribute to UFLS functionality. At present, this capability is typically used to selectively trip controlled loads at certain sites to deliver a UFLS response at higher frequency bands than the conventional (distribution network based) UFLS response.

This suggests that UFLS capability is feasible in AMI devices, although it is not widely available in most products available in the Victorian market at present. Trials, testing, and studies would likely be prudent to confirm his capability is adequately robust and reliable, before it is rolled out for wide-spread implementation.

What proportion of meters have UFLS capability?

In 2006, the Victorian Government mandated the rollout of electricity smart meters to all households and small businesses across Victoria under the Advanced Metering Infrastructure (AMI) program. Smart metering systems are now deployed at 98.9% of these Victorian customer connections at the time of writing[17].

At present, only household and small business AMI meters could be used for UFLS. They have a direct link to the load and/or supply contactor and can open the contactors to disconnect the customer's load. Larger commercial or industrial customers with current-transformer meters do not have a supply contactor, and so cannot be used in the same way as household and small business customers for UFLS. Different options may be available for these larger sites to enable UFLS functionality, such as an external control contactor. This has not been explored in this report but could be considered by NSPs in future work.

AEMO and NSPs worked with the meter manufacturers that supply the Victorian market and identified a list of the meter models in the field at present that could have UFLS functionality enabled. For these capable meter models, the hardware at the customer site has the UFLS capability already, and the manufacturer advised that this capability could be enabled via a remote firmware update (with no site visit or change of hardware required). Configuration 1 would see only a controlled load be disconnected by UFLS action at the customer meter, whereas configuration 2 would disconnect the entire customer site. To enable configuration 3, a combination of changes to customers' electrical installations and changes to the DNSP's metering installation would be required so that customers' load and generation are separately controllable.

Of the household and small business AMI installed in the field in Victoria at present, preliminary estimates indicate that approximately 10% of household and small business meters are the model types that have UFLS capabilities, with coverage varying across DNSPs. Approximately 96% of these are configured such that they would trip the entire customer site (rather than only tripping customer load, while leaving any generation on site connected). Some are configured to trip controlled loads, but can be remotely configured to point to the main supply contactor and trip the entire site via a firmware upgrade.

The assessment in this report to estimate the load that could be available from AMI UFLS has been conducted based on two sensitivities:

1. **UFLS at capable AMI** – Assuming only the "UFLS capable" AMI in the field at present contribute to net UFLS load. This gives an estimate of what might be feasible in the near-term, with firmware updates and without any replacement of physical infrastructure or customers' wiring at customer sites. This sensitivity is based on AMI mapping data provided to AEMO by VIC DNSPs where available, and an estimate based on DNSP meter coverage where mapping data was not available.
2. **UFLS at all household and small business AMI** – Assuming that UFLS is enabled at all household and small business AMI for whole-site shedding (configuration 2). This sensitivity gives an upper bound on existing AMI UFLS capability for cases where a mapping of the exact meter models on the sub-transmission loop with UFLS capability was not available. Actual enablement of this capability would likely require replacement of physical AMI infrastructure at most household and small business customer sites.

For both above sensitivities, it is assumed that Configuration 2 is applied (the AMI trips the entire customer site if the site is a net load, including all load and any generation on site). Sites that are net exporters are not tripped.

[17] NEM Interval Metering and Distributed Energy Resources: https://www.aemo.com.au/energy-systems/electricity/national-electricity-market-nem/data-nem/metering-data/nem-der-and-interval-metering-dashboard

Can AMI selectively arm/disarm UFLS based on site imports/exports?

Utilisation of AMI UFLS functionality in Configuration 2 requires that the meter can detect if the site is a net importer or net exporter, and selectively arm UFLS functionality in real time only if the site is importing (a net load).

The two predominant manufacturers of currently installed Victorian AMI have indicated that this capability should be feasible to implement with a firmware upgrade that has an algorithm to selectively arm UFLS at the meter if the site is a net load.

How would this affect the distribution network?

In the long term, the possibility of tripping all customer load on a feeder with predominately households and small businesses, while leaving all distributed generation connected and operating on that feeder raises important questions regarding the impacts on distribution feeder voltages and other protection systems. These would need to be explored by DNSPs as part of their feasibility assessment in considering rollout of this option.

Inverter-based distributed resources are required to meet Australian Standard AS/NZS4777.2:2020, which includes requirements that inverters trip if voltage exceeds certain thresholds for more than 0.2s. The sudden trip of a large proportion of load on a feeder (while generation continues operating) could lead to a rapid voltage rise, that could possibly be in the range that would lead to distributed inverters tripping on these passive anti-islanding voltage limits, before the voltage rise can be arrested by normal distribution voltage control mechanisms. The disconnection of generation would undermine the intention of the UFLS scheme (which is seeking to arrest an under-frequency event by disconnecting load while leaving generation operating). Disconnection of load might also lead to overloading of network assets due to reverse power flows, which could permanently damage critical and expensive infrastructure.

Related issues have been highlighted in studies by ISO New England (ISO-NE) exploring impacts of DER on UFLS[18]. Their studies showed that loss of load due to UFLS action can cause bus voltages to rise to a level and for a duration that may exceed the trip settings of utility-scale DER, causing the utility-scale DER to trip. This may mean that due to the additional generation deficiency, the island frequency may not recover.

These aspects and any other possible distribution network impacts need to be explored as part of the feasibility studies conducted by DNSPs (preferably coordinated by DNSPs for knowledge sharing and efficiency).

In the near term, with the relatively low levels of AMI UFLS response anticipated from the present UFLS-capable AMI infrastructure, implemented in Configuration 1 & 2, this is less likely to be a concern.

How would this capability be rolled out?

Metering coordinators use various types of networks to communicate with AMI. The flow of communication is usually from the AMI meters to the database of the metering coordinator via an interfacing software (providing meter readings of energy usage, voltage levels, and other information). However, this communication can also flow from the metering coordinator to the meters, for example to provide software updates to the meter.

[18] North American Electric Reliability Corporation (December 2021), NERC Reliability Guideline – Recommended Approaches for UFLS Program Design with Increasing Penetrations of DERs, Appendix D: Impacts of DERs on ISO-NE UFLS Islanding Study, page 41, https://www.nerc.com/comm/RSTC_Reliability_Guidelines/Recommended_Approaches_for_UFLS_Program_Design_with_Increasing_Penetrations_of_DERs.pdf

This means it may be possible in some cases to enable UFLS functionality at AMI meters via software updates (without a site visit required). This would be used to:

- Enable frequency trip settings at AMI devices, mapped to the distribution network.
- Implement an algorithm that only trips exporting customers (for customers in configuration 2).
- Bring customers back online in a controlled manner, following power system stabilisation AEMO's direction to NSPs that load can be restored.

Victorian DNSPs in their role as metering coordinators would need to investigate the feasibility of delivering these functions, and work with meter manufacturers and the mesh communications software supplier to implement required updates. Simultaneous coordination of a very large number of devices may be challenging, and outside of the design capabilities of existing systems, such that the capabilities of the communication software may need to be uplifted to fulfil these functions. In particular, it should be confirmed that the robustness of the mesh and point to point network is suitable for reconnecting customers, particularly considering a scenario where the communications network may be offline due to the power system event.

Regulatory frameworks

The AMI regulatory frameworks may require updates to allow implementation of UFLS functionality at individual customer sites via AMI devices. This may be complex. The Victorian AMI regulatory framework also has some unique elements which differ to other NEM regions, and would need to be considered in a bespoke manner.

There are also strict standards of electricity supply to customers which may need to be amended to allow for UFLS related outages at individual customer connection points.

Socio-economic impacts

The present configuration of UFLS, implemented at the 66kV level and with some sub-transmission loops in reverse flows, leads to a large number of customers being shed, with a net detrimental impact on the arrest of frequency when these loops are in reverse flows. In contrast, implementation of UFLS at individual customer sites allows a much smaller number of customers to be shed in a highly selective manner, only shedding customers where this provides a net benefit in arresting frequency. Overall, this should significantly improve outcomes for customers in two ways:

- Being more likely to successfully arrest frequency decline and thereby reducing the risk of a black system, and
- Shedding much fewer customers to achieve this outcome.

If UFLS action is successful, it is often possible to restore customer load within 30-60 minutes. If UFLS action is unsuccessful and a black system occurs, it can take 8-12 hours or longer to restore customer load. This means it is in all customer interests to achieve a successful arrest of frequency decline, and minimise the duration of the outage.

Enabling AMI in configuration 2 has some socio-economic considerations, including:

- Only customers that are net loads will be selectively shed. Since most customers with DPV are net exporters during the middle of the day, UFLS action at the customer could disproportionately impact customers that do not have DPV.

- When customers invest in on-site generation, they have incentives to move more load into the middle of the day. Investment in new loads such as electric vehicles will likely increase customers ability to utilise generation on-site and avoid exporting for a larger proportion of the time. This could affect the net load available via shedding in configuration 2.
- The experience of a UFLS event where only some customers are disconnected may be confusing to customers, leading to a high burden on network and retailer customer support, and a reduction in customer trust and confidence in network published notification of outages that do not reflect their experience.

These issues might be partially mitigated by separate control of customer load and generation, under configuration 3. Enabling UFLS via AMI may also provide further options to minimise customer impacts, by enabling tripping of controllable loads prior to more essential site loads, and enabling other forms of more selective shedding.

It is noted that multiple contingency events of the type that lead to triggering of UFLS are very rare, typically occurring once every few years. This means that the primary concern is the successful operation of the scheme to avoid a black system (and prevent a costly long duration outage with severe impacts on customers).

4 Case studies

4.1 Selection of case studies

Case studies were used to explore the different UFLS dynamic arming implementation approaches on a select subset of transmission loops. Four archetypes for sub-transmission loops were identified for these case studies in consultation with Victorian NSPs, as summarised in Table 3. The loops selected for case studies are actual 66 kV sub-transmission loops in the Victorian network, presented in an anonymised manner for the purposes of this report.

Table 3 The four case study loops identified

			
Household and small business sub-transmission loop	**Commercial sub-transmission loop**	**Sub-transmission loop with a large solar farm connected**	**Sub-transmission loop with a large wind farm connected**

4.2 Approach

For each loop, active power measurements from the following sources were used:

- 66 kV transmission use of system (TUoS) data.
- 22 kV data shared with AEMO by Victorian DNSPs.
- Anonymised customer smart meter data.

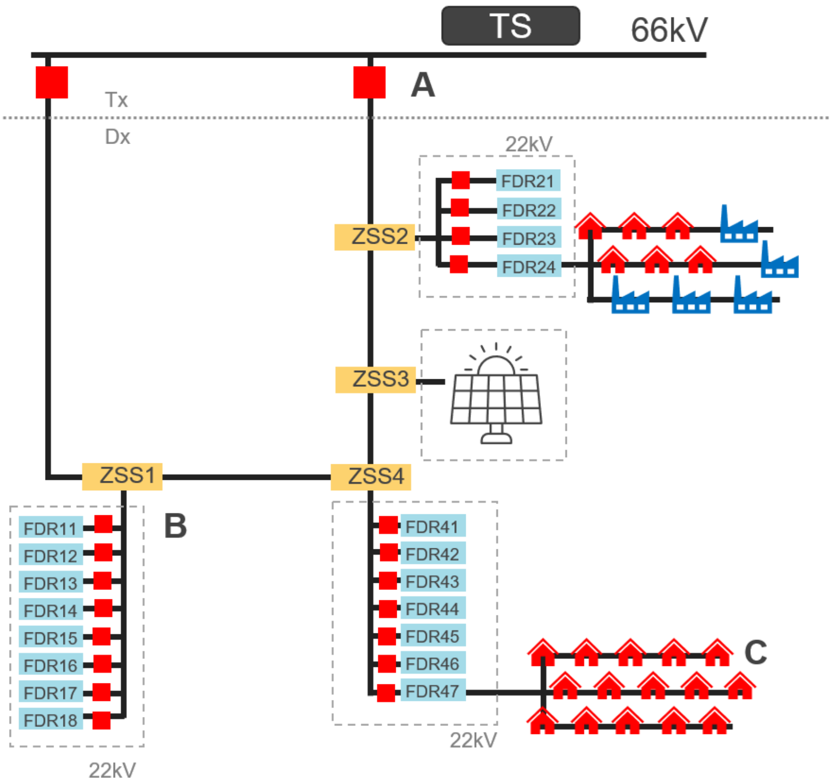
A mapping of customer National Metering Identifier (NMI) to distribution feeder was applied, provided by Victorian DNSPs. Where available, mapping for UFLS capable smart meter models to distribution feeders was also used.

The data was analysed as indicated in Table 4. This report considers the option of moving UFLS functionality to 22kV zone substations as a case study, but NSPs should consider each loop case-by-case and determine if a different voltage level may be more appropriate. For example, NSPs could consider implementation at distribution substations, as another alternative.

Table 4 Assessment approach

Remediation Action		Point in Figure 3	Approach
Base Case	Base case	A	Load measured at 66kV sub-transmission level
Option 1	Dynamic arming at the 66 kV level	A	Load measured at 66kV sub-transmission level, with reverse flow blocking
Option 2	Dynamic arming at the 22 kV level	B	Load measured at 22kV distribution zone substation level, with reverse flow blocking
Option 3	Dynamic arming at AMI	C	Load summed from household and small business customer AMI (represented by houses at point C in Figure 3). Sum of net importing sites only (if a site was a net exporter in a particular interval, it was not included in the sum). Only household and small business customers are included in the sum (industrial meters were not included).

Figure 3 Illustrative sub transmission loop with analysis points indicated



The red boxes and houses represent loads that can be disconnected via UFLS action.
TS: Terminal station
ZSS: Zone substation
FDR: 22kV feeder
Tx: Transmission network
Dx: Distribution network

4.3 Household and small business loop

This first case study focuses on a large 66kV sub-transmission loop servicing a large proportion of household and small business customers[19]. This sub-transmission loop is included in the existing UFLS scheme but has been

[19] Household and small business customers represent approximately 55% of daytime load on this loop.

identified as being a potential candidate for reverse flow blocking due to its high incidence of reverse flows (occurring around 1.8% of the time in 2021). These reverse flows are primarily due to DPV generation.

In 2021, the day with the lowest load on this loop was 28 November 2021. Figure 4 provides the daily load profile on this day, and shows the amount of UFLS load that would be available under each of the various implementation options. Observations are as follows:

- **Base Case: Relays at 66kV** – In the evening, the load on this loop is 60-100 MW. By midday, this falls to a reverse flow of -29 MW. If UFLS were triggered at midday, approximately 104,000 customers would be shed, and this would detrimentally affect power system frequency (exacerbating the frequency decline).
- **Option 1: Reverse flow blocking at 66kV** – Reverse flow blocking offers an improvement of 29 MW at midday (preventing trip of the loop when in reverse flows). It does not restore the 60-100 MW of underlying load that was originally in the UFLS scheme in daytime periods. If an under-frequency event occurred at midday in this configuration, the UFLS relays would be disarmed and no customers on the loop would be shed. The detrimental impact on power system frequency from shedding a loop in reverse flows would be avoided, but there would also be no contribution to arresting the frequency decline.
- **Option 2: Reverse flow blocking at 22kV** – Overnight, UFLS at the 22kV level is very similar to at the 66kV level. In the day, the UFLS load on 22kV feeders reaches a minimum of 11 MW (offering a further 11 MW improvement over reverse flow blocking at the 66kV level). Of the 35 22kV feeders on this loop, 25 feeders were in reverse flow in the middle of this day. This suggests some benefit from moving UFLS functionality to the 22kV level. However, as DPV levels continue to increase over time, it is likely that more 22kV feeders will move into reverse flow, deteriorating this value. This would need to be explored further before this option is pursued. In this configuration, if UFLS were triggered, approximately 21,000 customers who are on feeders that are net loads would be shed, and this would help to arrest the frequency decline by contributing 11 MW of net UFLS load. The 83,000 other customers on this loop who are located on feeders that are in net reverse flows would not be shed.
- **Option 3a: UFLS at all household and small business AMI (hypothetical)** – In overnight periods, the household and small business AMI load is lower than the 22kV/66kV measured load, due to the exclusion of commercial customers. However, in the middle of the day, if all household and small business customers hypothetically had UFLS capable AMI, the total load would be approximately 44 MW (offering a 44 MW improvement over reverse flow blocking at the 66kV level, and a 73 MW improvement from the existing UFLS arrangement). If this were hypothetically possible to access (acknowledging this would require changes to hardware at most customer sites), a UFLS event at midday would lead to approximately 72,000 household and small business customers being shed, providing a trip of net UFLS load of 44 MW. The other 32,000 customers that are exporting at midday (or are commercial customers) would not be shed.
- **Option 3b: UFLS at capable AMI (available without hardware changes)** – When accounting for only the AMI models in the field that are likely to be UFLS-capable at present, known to be connected to this sub-transmission loop[20], the load available for UFLS functionality in the middle of the day is approximately 8 MW. If a UFLS trip occurred at midday, approximately 18,000 customers would be shed, providing a net contribution

[20] Approximately 10% of all the household and small business AMI customers in Victoria at present have smart meters that would be able to perform UFLS after a firmware upgrade, including firmware changes to point the UFLS action from the load control contactor to the main supply contactor, as discussed in Section 3.3. The estimate presented here is based on an explicit mapping of known meter models at NMIs on this sub-transmission loop.

to UFLS arrest of frequency of 8 MW. The remaining 86,000 customers on the loop who are net exporters or who do not have a meter capable of UFLS functionality at present would remain connected.

Figure 4 Daily load profile for household and small business case study loop on 28 November 2021

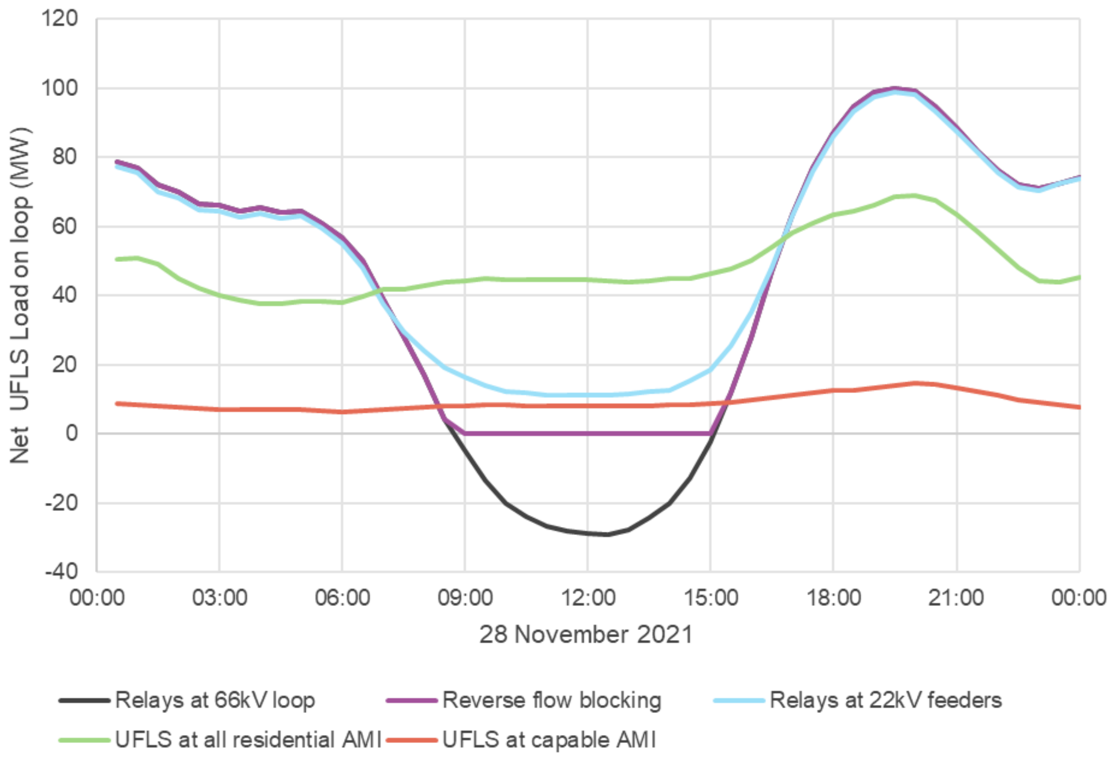


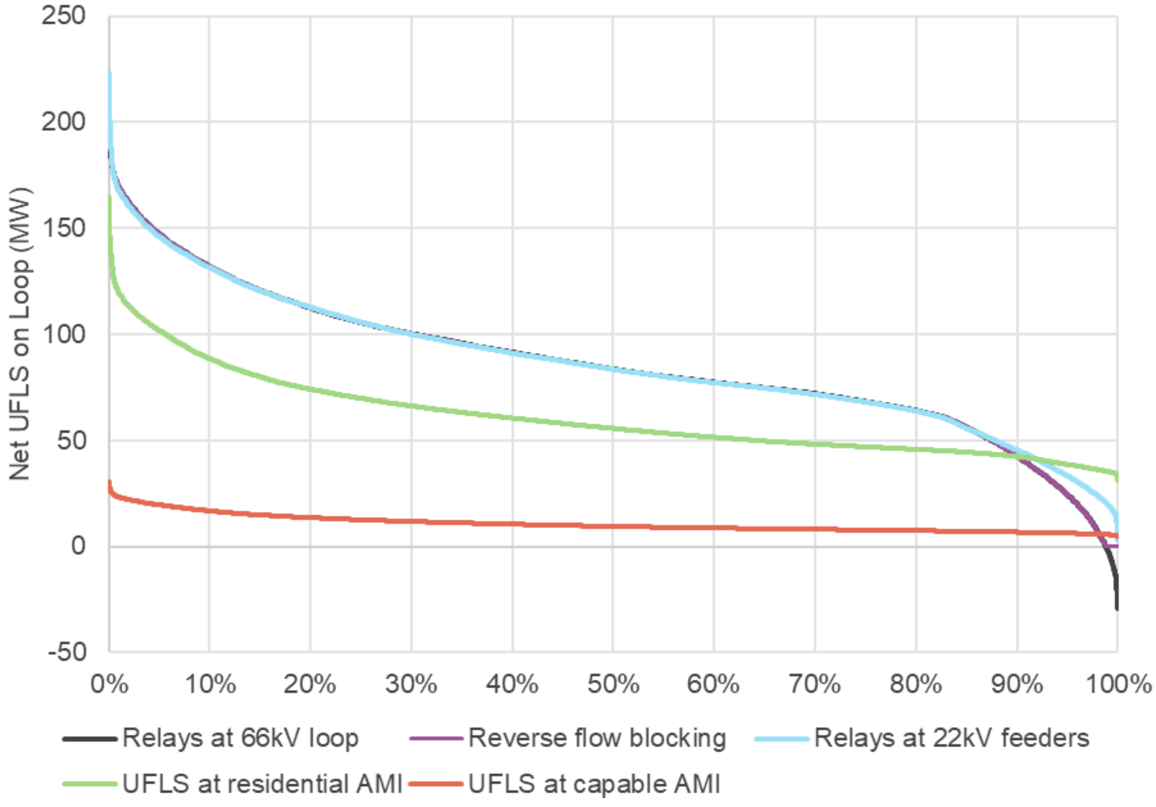
Table 5 shows the MW load shed in UFLS action and the approximate number of customers that would be shed for each option.

Table 5 MW load shed in UFLS action and number of customers affected at 12:00pm on 28 November 2021

	MW load shed in UFLS action	Number of customers shed	Number of customers that remain connected, compared with present UFLS configuration
Base Case: Existing UFLS configuration	-29 MW	~104,000	0
Option 1: 66kV with reverse flow blocking	0 MW	0 (No shedding with reverse flow blocking)	104,000
Option 2: 22kV with reverse flow blocking	11 MW	~21,000	83,000
Option 3a: UFLS at all household and small business AMI (hypothetical)	45 MW	~72,000	32,000
Option 3b: UFLS at all presently capable household and small business AMI	8 MW	~18,000	86,000

Figure 5 shows an annual load duration curve for this loop for 2021. Moving the UFLS relays to 22 kV would offer an improvement from the existing arrangement at the 66 kV levels for ~10% of the year. Moving the relays to UFLS-capable customer AMI offers an improvement over the present arrangement for ~3% of the year, although this is likely to increase over time as DPV levels continue to increase.

Figure 5 Annual load duration curve for the household and small business loop case study (2021)



Option assessment

For this loop, it appears that it may be worth further exploration of the AMI UFLS option. Utilising only existing hardware, this appears to offer almost as much net UFLS load as a move of UFLS functionality to the 22kV level. If it is possible to enable UFLS via AMI with remote firmware updates only (no site visits required) it is possible that this would offer a lower cost option that provides almost as much net UFLS load as the 22kV option. It also results in shedding of fewer customers if an UFLS event occurs, compared with shedding at the 22kV level. It may be more robust over the longer term as DPV levels continue to grow, although this has not been quantified in this analysis, and may require an evolution towards AMI configuration 3 (with load and DPV on separate contactors).

It appears that moving relays to the 22kV level at this loop might offer a small short term improvement in UFLS load in ~10% of periods, but this may not be warranted given the expectation of continuing DPV growth which may reduce the value of this investment over time. Trialling the use of AMI technology in this context may offer more longer term benefits.

This analysis suggests a hybrid solution could be worthy of further investigation. This might be implemented as follows:

- Introduce dynamic arming of UFLS at the 66kV level. The 66kV UFLS relays at this loop could be programmed to disarm when measured net load at the 66kV level falls below a pre-defined threshold (this analysis suggests a threshold of approximately 8.5 MW for this loop[21]).
- Implement UFLS functionality on all UFLS-capable AMI on this sub-transmission loop. To minimise real-time complexity, AMI trip settings could be enabled in all periods, if frequency settings are aligned with the associated 66kV relay at this loop.

This hybrid arrangement would facilitate conventional UFLS operation (at the 66kV level) ~97% of the year, but in the ~3% of periods where UFLS load on the loop falls very low, enables UFLS capability via capable customer AMI on the loop instead[22]. The percentage of time with UFLS operation at the AMI level could be expected to increase over time, as further DPV continues to be installed on this loop.

This case study suggests that if dynamic arming is being introduced at any existing 66kV UFLS locations, it would be valuable to include the capability to remotely adjust the dynamic arming threshold to a non-zero number. It may be preferrable to disarm relays at a level higher than 0 MW (before they go into reverse flows) if hybrid solutions of this type become available over time to facilitate more granular load shedding downstream.

Further hybrid options may be worth considering for some sub-transmission loops; for example, in some locations, it may be worth considering implementation of UFLS reverse flow blocking at the 22kV level (or another intermediate voltage level) in conjunction with UFLS via AMI in the lowest load periods. This analysis suggests that for this particular sub-transmission loop this combination offers minimal benefit beyond reverse flow blocking at the existing 66kV level in combination with UFLS via AMI, so the additional costs of implementing UFLS at the 22kV level may not be warranted. However, these additional possible hybrid options should be explored case-by-case by NSPs.

Next steps

Given the novelty of implementing UFLS at customer AMI, a suitable approach might be to start with preliminary investigation and a trial, such as:

- Investigation phase:
  - NSPs investigate feasibility (addressing questions and topics summarised in Section 3.3)
- Trial phase:
  - NSPs determine a selection of sub-transmission loops with a high proportion of household and small business load (similar to the one investigated in this case study).
  - NSPs work with the relevant AMI manufacturers to develop and implement a firmware update for all UFLS-capable AMI on these sub-transmission loops, to enable UFLS capability selectively for AMI on these loops.
  - Confirm adequate performance, and develop learnings.

A trial could allow DNSPs to develop learnings and inform possible longer term options for EFCS adequacy. If successful, such a trial might also inform future review of Victorian AMI minimum meter specifications for

[21] This would be determined case by case, depending on the actual implementation design for each loop, determining the level at which 66kV UFLS should be disarmed because a larger amount of net load is typically available from aggregate UFLS-capable AMI on the loop. For this loop, in the historical year of analysis (2021), it was found that the net load at the 66kV level typically falls lower than the aggregate total net load from all UFLS-capable AMI on this loop when net load at the 66kV level is measured at approximately 8.5 MW.

[22] These estimates are based on disarming of the 66kV UFLS when net load on the loop falls below 8.5 MW.

new/replacement meters to possibly include UFLS functionality, and/or involve separate contactors for separated shedding of load and generation on site. If this were to be pursued in future, this would need to consider the impacts on customers from implementing a different meter configuration, with specific consideration to social license and the practicality and costs relating to changes to customer electrical installations.

4.4 Commercial loop case study

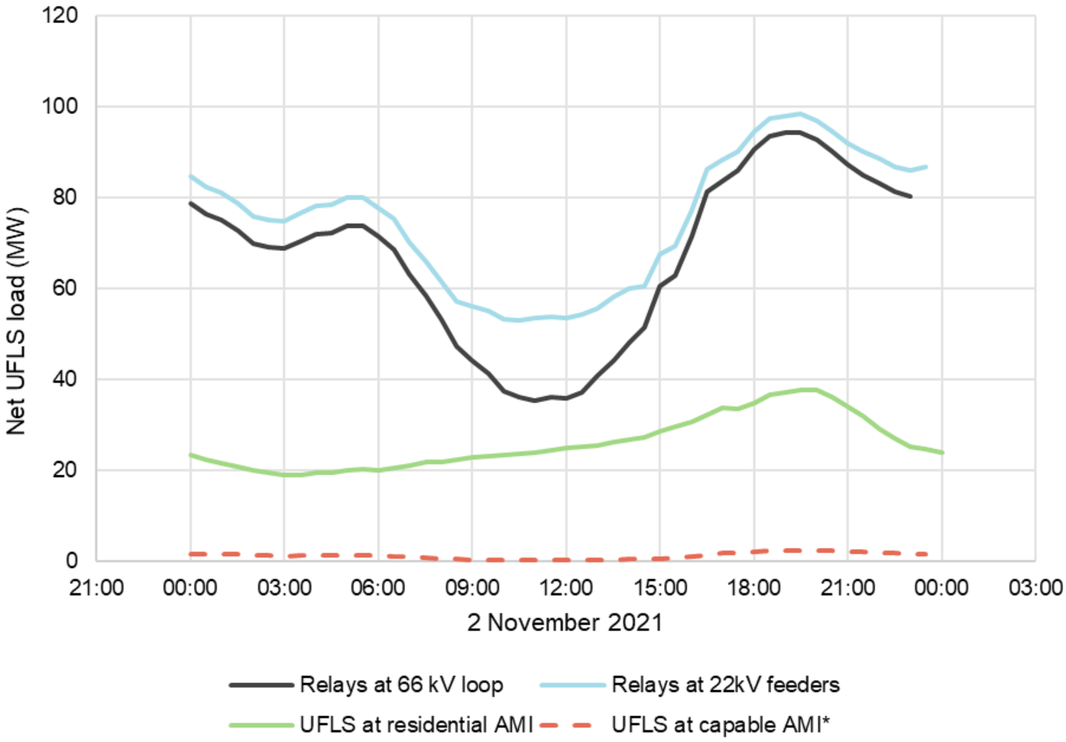
This case study focuses on a 66kV sub-transmission loop with a high proportion of commercial and industrial customers[23]. This sub-transmission loop is not in the UFLS scheme at present, but has been identified as a candidate to be added to the scheme in the Stage 1 work program.

Figure 6 shows the daily load profile for this commercial loop on a representative low load day (2 November 2021), illustrating the net load on the UFLS scheme under each of the implementation options. Observations are as follows:

- **Base Case: Relays at 66kV** – In the middle of the day, the minimum load measured at the 66 kV level was 36 MW. This increases to approximately to 94 MW during the evening peak. The net load on this loop appears to be somewhat reduced by DPV during daytime periods, but does not go into reverse flows.
- **Option 1: Reverse flow blocking at 66kV** – The load at the 66 kV level with reverse flow blocking is not illustrated, because this loop did not have any reverse flows in 2021. Reverse flow blocking at the 66kV level would therefore offer no benefit at this sub-transmission loop, at present.
- **Option 2: Reverse flow blocking at 22kV** – The net UFLS load at the 22kV level is higher than the load at 66 kV level because there are certain feeders that have landfill gas generators on this loop which would be removed from the UFLS scheme with UFLS implementation at the 22kV level. During the middle of the day, the load at the 22 kV level is approximately 54 MW, an improvement of around 18 MW compared with load at the 66kV level. This is due to 22 kV loops that have high levels of DPV with reverse flows at the 22kV level. Of the 44 22 kV feeders on this loop, 10 feeders were in reverse flow on this day, including one landfill gas generator.
- **Option 3a: UFLS at all household and small business AMI (hypothetical)** – The net load available from all household and small business customer AMI (if these hypothetically had UFLS capability) is significantly lower than the other two options on this loop for this day, at approximately 25 MW in the middle of the day. This loop features a large proportion of commercial/industrial load. These larger customers have current-transformer meters which do not have direct control of the load and are not able to be included in UFLS action via AMI (although there may be other technology options that could be implemented at the customer site if desired).
- **Option 3b: UFLS at capable AMI** – The DNSPs associated with this sub-transmission loop have very few AMI models in the field that have UFLS functionality at present, estimated at approximately 0.4MW of load in the middle of the day, and approximately 2.5 MW over the evening peak.

[23] Commercial and industrial customers represent approximately 60% of daytime load on this sub-transmission loop.

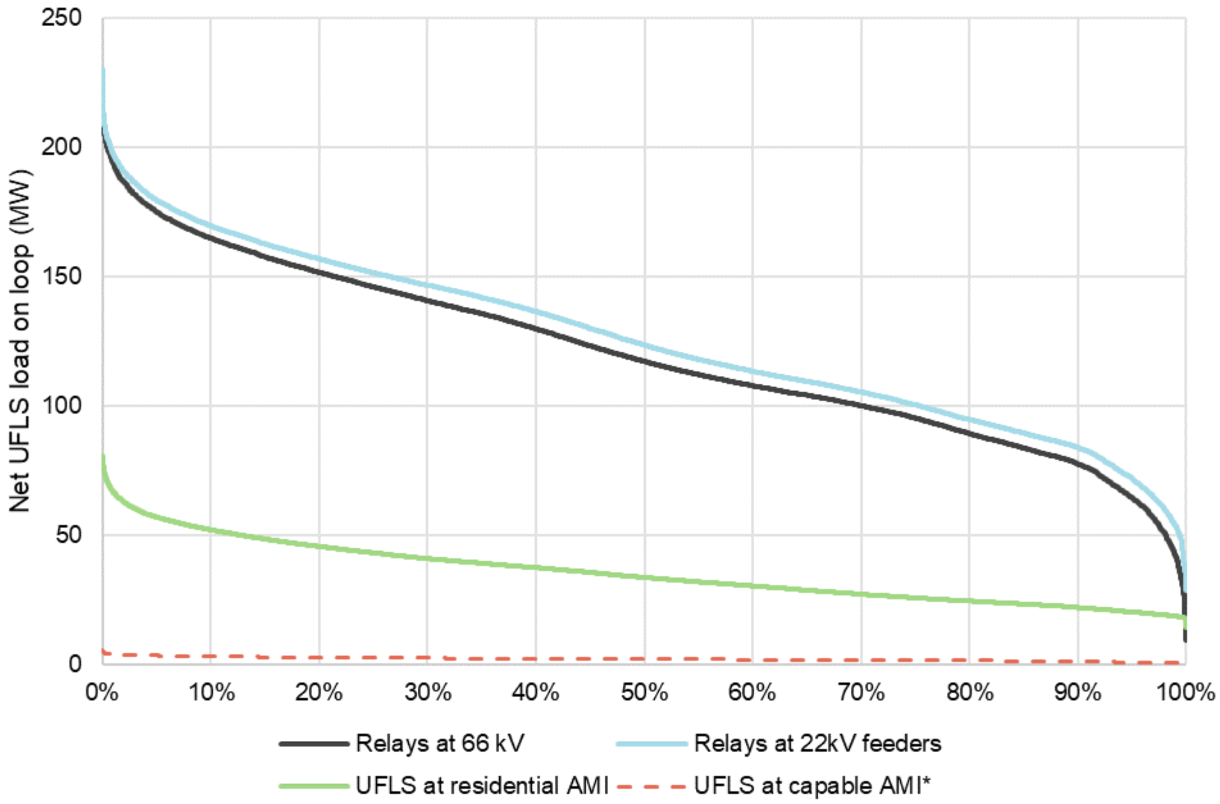
Figure 6 Daily load profile for commercial loop on 2 November 2021



* The value for UFLS at capable AMI is estimated based on average DNSP coverage of UFLS capable meters.

Figure 7 shows the annual load duration curve for this commercial loop case study for 2021. Moving the UFLS functionality to the 22 kV level offers a 5-15 MW increase to the load available on this loop for the entire year, due to exclusion of the landfill gas generators from the UFLS tripping action. In 2021, the amount of load available from household and small business AMI is substantially less than that available at the 22 kV and 66 kV level.

Figure 7 Annual load duration curve for commercial loop case study (2021)



* The value for UFLS at capable AMI is estimated based on average DNSP coverage.

Option assessment

Based on the 2021 year, moving UFLS functionality to the 22 kV level restores the most load to this commercial case study loop, and offers an increase of UFLS load in all periods, up to a maximum of ~18 MW (this amount is likely to increase over time if DPV installations continue on this loop).

The low level of load from household and small business customers and high proportion of commercial/industrial customers on this loop do not make it a good candidate for UFLS at household and small business AMI. Other options may be available for UFLS-functionality at the customer site for commercial/industrial customers.

4.5 Solar farm case study

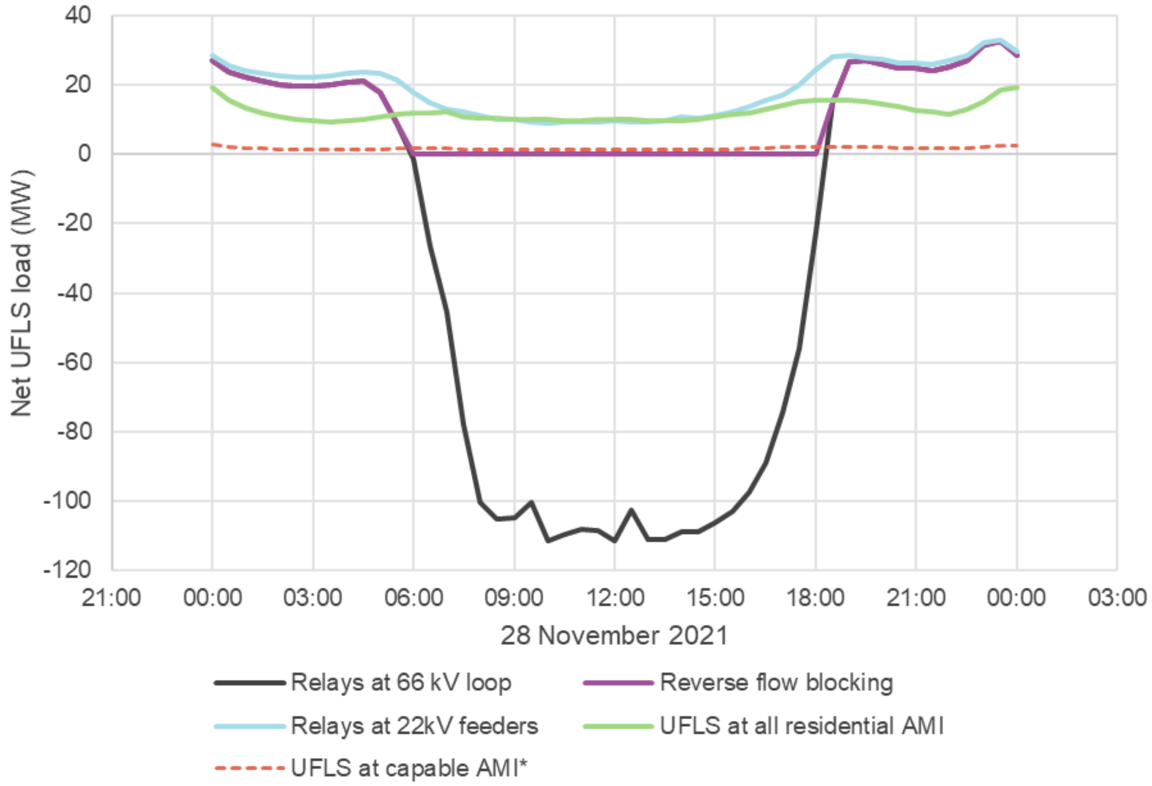
This case study focuses on a 66kV sub-transmission loop with a large (>100 MW capacity) solar farm and two zone substations. This sub-transmission loop is in the existing UFLS scheme but has been identified as a candidate to be removed from the scheme in Stage 1 due to its high incidence of reverse flows (observed to be in reverse flows 34% of the time in 2021).

Figure 8 shows the daily load profile for this loop for an illustrative low load day on 28 November 2021, with the net UFLS load available under various UFLS implementation options. Observations are as follows:

- **Base Case: Relays at 66kV** – The minimum load reached is -112 MW in the middle of the day, due to solar farm generation.

- **Option 1: Reverse flow blocking at 66kV** – Reverse flow blocking at this site prevents the UFLS relay being activated under reverse flow conditions (offering a ~100 MW improvement) but does not restore any of the underlying load.
- **Option 2: Reverse flow blocking at 22kV** – With implementation of UFLS functionality with reverse flow blocking at the 22 kV level, total net load is around 9.5 MW in the lowest part of the day (compared with 20-30 MW of load on this loop overnight). This offers a further 9.5 MW improvement over Option 1.
- **Option 3a: UFLS at all household and small business AMI (hypothetical)** – The load from all household and small business AMI on this loop (if they hypothetically had UFLS capability) is similar to that enabled at the 22kV level during the middle of the day (~9.5MW). During night periods, the household and small business AMI load is lower than measured at the 66kV level, due to the exclusion of commercial customers.
- **Option 3b: UFLS at capable AMI** – The DNSP associated with this sub-transmission loop has approximately 14% of their AMI fleet in the field with UFLS functionality at present, suggesting that activation of this capability on the existing fleet where feasible might deliver 1.3-1.4 MW of net UFLS load in the middle of this day.

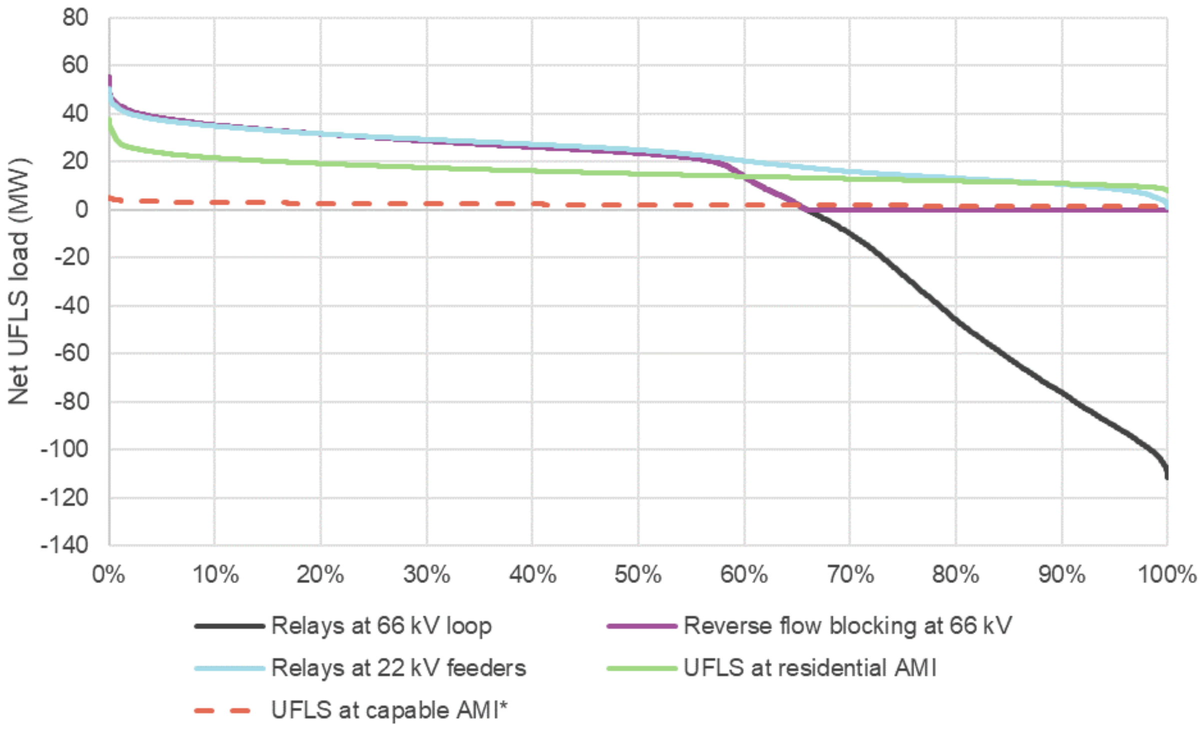
Figure 8 Daily load profile for solar farm loop case study on 28 November 2021



* The value for UFLS at capable AMI is estimated based on average DNSP coverage.

Figure 9 shows the annual load duration curve for this loop for 2021. This loop is in reverse flow at the 66kV level for approximately 34% of the year. For approximately 45% of the time, the UFLS load available from 22 kV feeders with reverse flow blocking is greater than the 66 kV level, suggesting this may be an effective option at this location (if the costs of implementing relays at the 22kV level are feasible). The UFLS load available from customer AMI on this loop is only greater than all other options for around 10% of the year, and is likely much lower than this level in practice, if only the UFLS-capable AMI are included.

Figure 9 Annual load duration curve for solar farm case study (2021)



* The value for UFLS at capable AMI is estimated based on average DNSP coverage.

Option assessment

This analysis suggests that implementing UFLS relays at the 22kV level may be appropriate at this sub-transmission loop, if the costs of this option are feasible. Reverse flow blocking at the 66kV level also offers a substantial improvement over the present base-case. Complete removal of the loop from the UFLS scheme (as proposed in Stage 1 remediation actions) removes the negative impacts of up to 100 MW reverse flows in daytime periods, but also removes the 20-40MW of load available on this loop from the UFLS in the 65% of the year when the loop is not in reverse flows.

Over time, with further growth in DPV, the load available at the 22kV level may further decrease (not assessed in this analysis). In this longer timeframe, UFLS from AMI may become a suitable alternative, particularly if this capability can be implemented on more AMI infrastructure over time, set up in Configuration 3 (load and DPV on separate meter control contactors), with considerations as per the household and business loop case study.

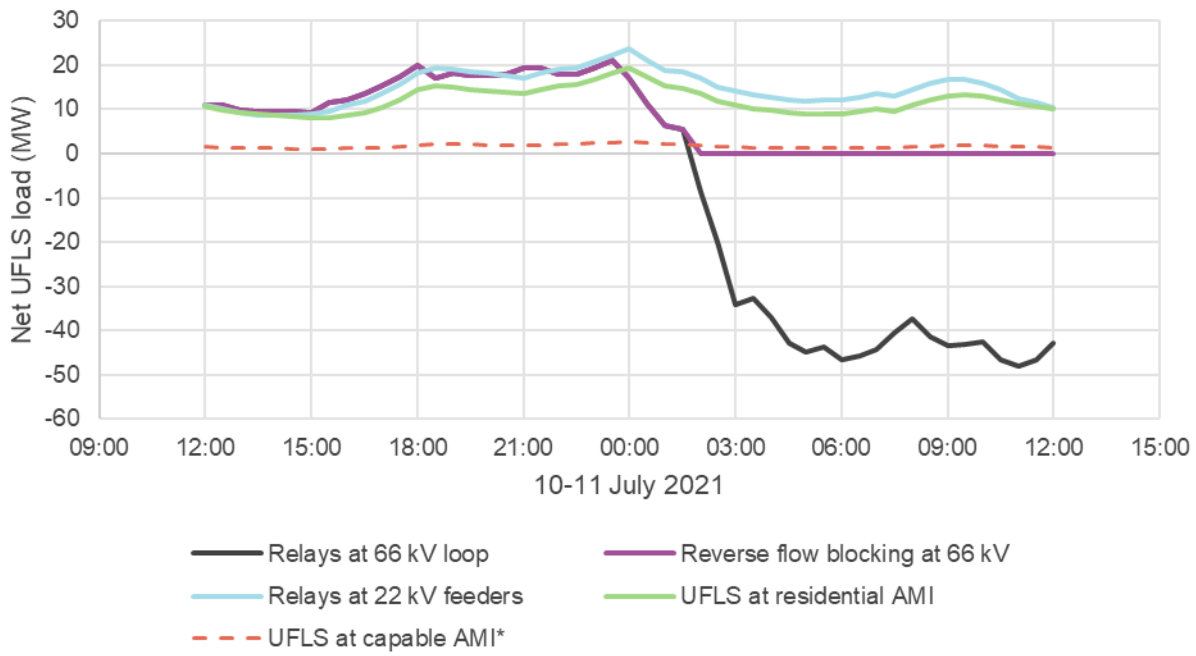
4.6 Wind farm case study

This case study focuses on a 66 kV sub-transmission loop with approximately 80 MW of wind farm capacity connected to the loop. This sub-transmission loop is in the existing UFLS scheme but has been identified as a candidate to be removed from the scheme in Stage 1 actions due to its high incidence of reverse flows (in reverse flows ~64% of the year in 2021).

Figure 10 shows the daily load profile for this loop for a representative 24hr period on 10 - 11 July 2021, with the net UFLS load available via the various implementation options. Observations are as follows:

- **Base Case: Relays at 66kV** – The load measured on the 66 kV loop reaches a maximum of 20 MW during the night, before the wind generation increases and pushes the entire loop into reverse flow, reaching a minimum of -48 MW at around 11:00 AM on 11 July.
- **Option 1: Reverse flow blocking at 66kV** – Reverse flow blocking at this site prevents the UFLS relay being activated under reverse flow conditions (offering a ~48 MW improvement in these periods) but does not restore the underlying load.
- **Option 2: Reverse flow blocking at 22kV** – With implementation of reverse flow blocking at the 22 kV level, total load remains at around 10-20MW throughout the 24hr period. This offers a further 10-15 MW improvement over Option 1.
- **Option 3a: UFLS at all household and small business AMI (hypothetical)** – The load from all household and small business AMI on this loop (if they all hypothetically had UFLS capability) is similar to that enabled at the 22kV level.
- **Option 3b: UFLS at capable AMI** – The DNSP associated with this sub-transmission loop has approximately 14% of their AMI fleet in the field with UFLS functionality at present, suggesting that activation of this capability on the existing fleet where feasible might deliver around 1-2.5 MW of net UFLS load.

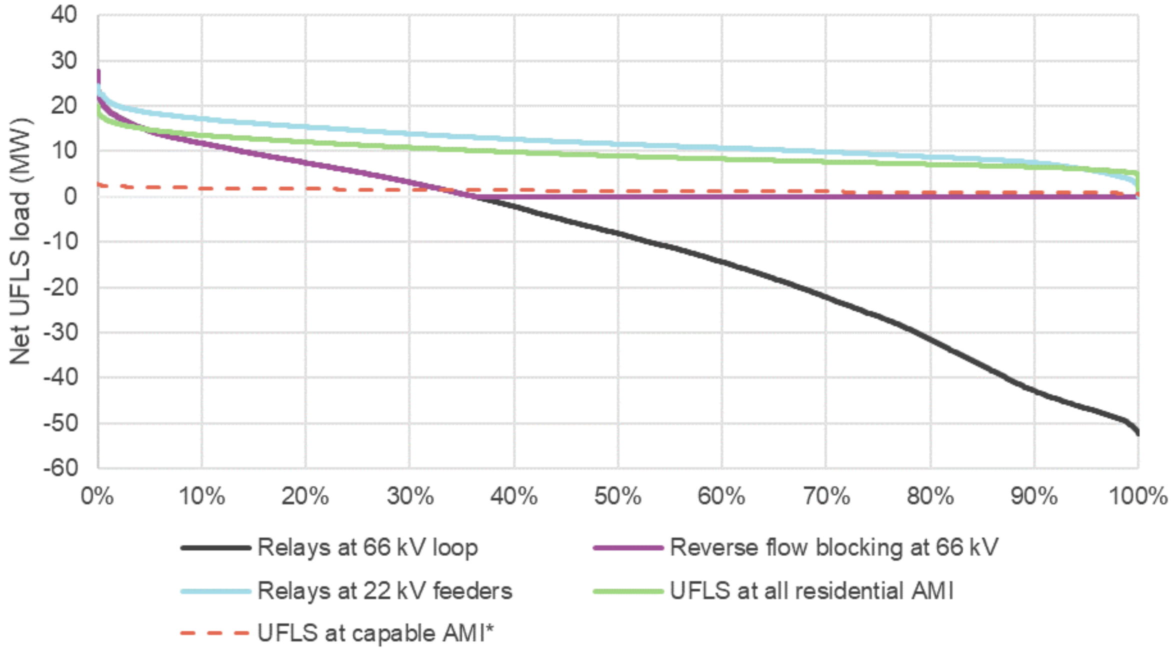
Figure 10 Daily load profile for wind farm loop case study from 12:00 10 July to 12:00 11 July 2021



* The value for UFLS at capable AMI is estimated based on average DNSP coverage.

Figure 11 shows the annual load duration curve for 2021 for the wind farm case study. The net load on the 66 kV network is in reverse flow for approximately 64% of the year. The net UFLS load at the 22 kV feeder level remains greater for this case study loop for approximately 95% of the year. For approximately 5% of the year, the load from customer AMI is the highest, although actual enablement available at existing UFLS-capable AMI is likely much lower than this level.

Figure 11 Annual load duration curve for wind farm case study (2021)



* The value for UFLS at capable AMI is estimated based on average DNSP coverage.

Option assessment

For this case study, moving UFLS relays to 22 kV feeders would restore the largest amount of UFLS load in the majority of periods, compared to other options.

In the longer term, continuing growth in DPV may further reduce the net UFLS load available at the 22k V level, and implementation of UFLS capability at AMI may be preferrable, particularly if AMI infrastructure replacement at customer sites over time is specified to include new UFLS capabilities and implementation in Configuration 3 (load and DPV on separate meter control contactors), with considerations as per the household and business loop case study.

5 Summary of findings

Table 6 provides a summary of the net load available to contribute to the UFLS scheme for each option considered, in each archetypal loop. The options that appear most promising for further investigation in each case are highlighted in green.

Table 6 Summary of load in lowest period

	Net UFLS load in lowest load period (MW)			
	Household and small business loop	**Commercial loop**	**Solar farm loop**	**Wind farm loop**
Analysis period	28 November 2021	2 November 2021	28 November 2021	10-11 July 2021
Base Case: Existing UFLS configuration	-29 MW	35 MW	-112 MW	-48 MW
Option 1: 66kV with reverse flow blocking	0 MW	35 MW	0 MW	0 MW
Option 2: 22kV with reverse flow blocking	11 MW	53 MW	10 MW	10 MW
Option 3a: UFLS at all household and small business AMI	45 MW	25 MW	10 MW	10 MW
Option 3b: UFLS at all presently capable household and small business AMI	8 MW	~1 MW	~1.3 MW	~1.3 MW

The case studies suggest that the optimal options for each sub-transmission loop will likely differ, and should be considered case by case.

Household and small business loops

For the case study loop with a large proportion of household and small business load, it appears that enabling UFLS via AMI that are capable of this functionality at present might offer a similar level of net UFLS load as implementing new UFLS relays at the 22kV level. This suggests that it may be appropriate for NSPs to explore the AMI option further, since it could represent a lower cost alternative in some locations to moving UFLS functionality from 66kV to a lower voltage level (and may also be more robust over the longer term as levels of distributed resources continue to grow, although future projections have not been explicitly quantified in this report).

The case study suggests this option could be implemented as a hybrid arrangement, with dynamic arming introduced at the existing 66kV level and delivering normal UFLS functionality in most periods (conventional load shedding at the 66kV level would continue to apply approximately 97% of the time in 2021). The 66kV UFLS relays would be programmed to disarm when net demand on the loop at the 66kV level falls below a non-zero threshold (estimated at approximately 8.5 MW for this case study sub-transmission loop in 2021). For periods with lower demand levels (approximately 3% of the time in 2021, and likely to increase as DPV levels continue to grow), shedding at the 66kV level would be automatically disabled, and dynamic arming at capable AMI sites would instead apply, shedding individual customer sites that are net loads only, if power system frequency falls below the pre-determined thresholds.

Given the novel nature of this option, and the likely long lead times to develop it towards implementation, this case study suggests it may be prudent for DNSPs to consider further exploration of this option as a trial on a selection of sub-transmission loops that have a high proportion of household and small business load. This could allow DNSPs to develop learnings and inform possible longer term options for EFCS adequacy. If successful, such a trial might also inform future review of Victorian AMI minimum meter specifications for new/replacement meters to possibly include UFLS functionality, and/or involve separate contactors for separated shedding of load and generation on site. Such a review would need to consider practical implications and costs for consumers in changes to electrical infrastructure on customer sites.

Commercial loops

For the case study loop with a large proportion of commercial load, moving UFLS functionality to the 22kV level appears to be a suitable option in the near term. There are minimal UFLS-capable AMI on commercial loops, so the AMI option is not available with present hardware. Commercial loops can include embedded generators connected at the 22kV level, which can be excluded from UFLS if relays are moved to a lower voltage level.

It may be worthwhile for DNSPs to explore other (non-AMI) alternatives to enable UFLS functionality at individual commercial/industrial customer sites, particularly if these customers are in the process of commissioning on-site generation, or during the commissioning process for new load connections.

Loops with large wind/solar farms

For loops with large generators connected at the 66kV level, moving UFLS functionality to the 22kV level offers a significant and immediate increase in net UFLS load by excluding the large wind and solar generators from tripping via UFLS. This case study suggests this may be a suitable option for these loops in the near term.

For loops that also have a high proportion of household and small business load, the amount of net load available at the 22kV level may deteriorate over time as DPV levels continue to increase, and the value of exploring AMI UFLS options may improve over time.

6 Next steps

AEMO is working on assessing the adequacy of EFCS to arrest plausible multiple contingency events that could occur in periods with low demand and high generation from DPV. This ongoing analysis aims to account for the evolution of the power system in many dimensions, such as:

- including the effects of large battery energy storage systems (BESS) and other inverter based resources (IBR) which can provide fast frequency response and help to arrest a rapid frequency decline,
- the complex interactions and dynamics of DPV and load tripping behaviours during UFLS tripping timeframes,
- changing dispatch patterns and interconnector flows which will lead to changes in the size of plausible multiple contingency events that could occur, and
- accounting for new risks, such as cybersecurity.

As this analysis progresses, AEMO intends to provide further advice to NSPs and the Australian Energy Regulator (AER) on the adequacy of EFCS to inform further work NSPs may need to undertake to maintain adequate EFCS functionality.

In parallel, AEMO has informed NSPs on the declining levels of UFLS load[24,25], which is likely to affect UFLS functionality. AEMO recommends that NSPs proactively consider options for improving EFCS functionality, so that any remediation required can be progressed in a timely manner on receiving AEMO's advice. This analysis suggests that some cost-effective options might be relatively novel, and will require trials and extensive investigation prior to wide-spread implementation and investment. This highlights the importance of NSPs proactively initiating early investigative work. NSPs will need to consider suitable funding pathways for resourcing this work.

These early case studies suggest it would be prudent for Victorian NSPs to further investigate the areas outlined in Table 1.

Table 7 Recommended areas for further investigation by Victorian NSPs

Topic	Details
Sub-transmission loops with large wind/solar farms	Explore options for addressing reverse flows on sub-transmission loops with large wind/solar farms behind UFLS relays.
Generator connection processes	Update generator connection processes to consider and address impacts on UFLS, aiming to ensure future large generating units are not connected behind UFLS relays.
AMI UFLS feasibility	Explore the many outstanding questions to assess feasibility of UFLS via AMI. This includes: • Clarifying costs and rollout pathways, and the proportion of capable AMI in the network. • Confirming the UFLS tripping functionality available in AMI is adequately fast (~200ms) and adequately robust, and will not lead to excessive maloperation. • Confirm or develop suitable communication systems with AMI to manage UFLS functionality in real-time, including restoring customers in a timely manner. • Developing an understanding of the possible implications for the low voltage network from tripping a large proportion of customer load via AMI, while leaving DPV generating. In particular, consider possible overload of distribution network elements, and explore the possibility of a transient high voltage spike that could lead to AS/NZS4777.2:2020 compliant

[24] 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?la=en&hash=A72B6FA88C57C37998D232711BA4A2EE

[25] AEMO (May 2023) Victoria: UFLS load assessment update, https://aemo.com.au/-/media/files/stakeholder_consultation/consultations/nem-consultations/2022/psfrr/2023-05-25-vic-ufls-2022-review.pdf?la=en&hash=CFDBA2D60117E8E7FE452B2C2F468B3B

Topic	Details
	inverters disconnecting on passive anti-islanding voltage limits (which could defeat the intention of UFLS via AMI). • Exploring the suitability of the present regulatory framework for AMI, and identify and address any barriers for application of AMI in this manner. • Suitable consumer engagement and development of social license for this approach • Quantifying the robustness of this approach versus other options in future projections, with continuing growth in DPV.
AMI UFLS trial	Consider establishing a trial implementation of UFLS via AMI for existing capable meters on selected sub-transmission loops, to develop learnings and inform possible future options.

A1. Implementing UFLS functionality at AMI

This appendix provides a summary of further details for consideration when exploring possible implementation of UFLS functionality at AMI.

A1.1 Description of the desired outcome

If UFLS functionality were implemented at AMI, meters would have frequency trip settings implemented locally, such that the meter autonomously and automatically disconnects any net load on the customer site when frequency falls below pre-defined thresholds. Frequency trip settings would be diversified across the various meters in the region (with settings at each customer site ranging between 49Hz and 47.5Hz) to produce a progressively larger load disconnection for a deeper frequency disturbance. This aims to replicate the functionality of the existing UFLS scheme, which is outlined in more detail in section A1.2.

Essential features include:

- Ability for each meter to autonomously measure and detect a rapid and severe drop in frequency of the power system, and autonomously disconnect customer load on the site within ~200ms of frequency falling below a pre-determined threshold.
- Ability for each meter to avoid spurious tripping due to frequency transients, voltage disturbances, phase angle jumps and other types of disturbances (explored further below).
- Ability for each meter to autonomously determine if the customer site is importing or exporting in a particular time interval, and dynamically arm the frequency trip setting if the site is importing, or disarm the frequency trip setting if the site is exporting.
- Ability to reconnect and restore the customer load later (approx. 30-60min following disconnection), preferably in a centrally controlled manner when DNSP receives a direction from AEMO control room.
- Ability to implement and update these settings in a large number of meters in the field without a site visit or changes to hardware and circuitry required, and to achieve this selectively (targeting meters on specific loops with individually configured settings).

A1.2 Sequence of operation for UFLS

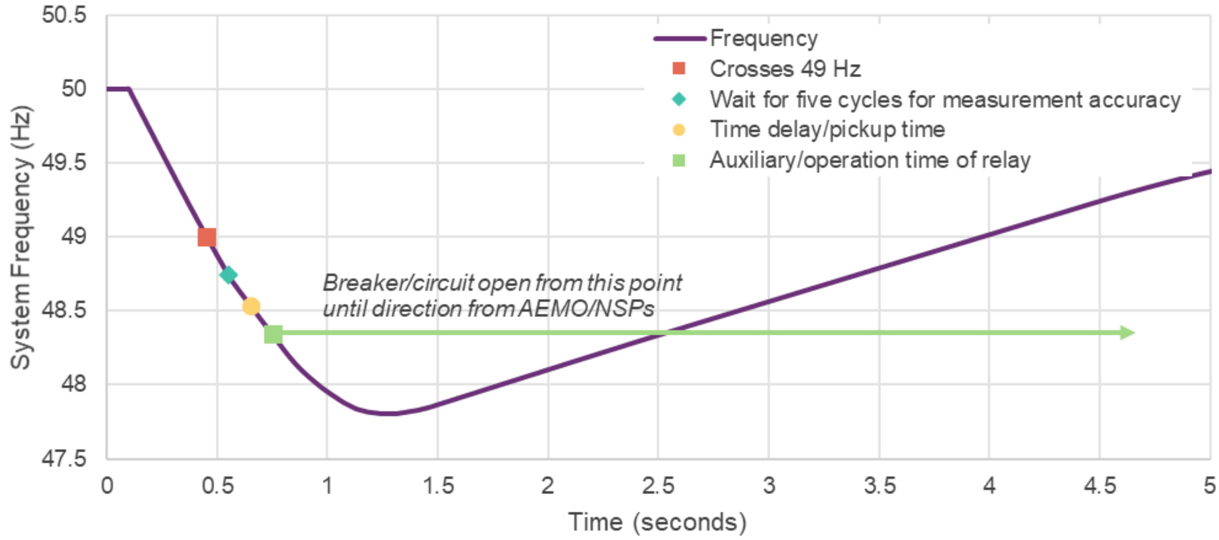
Figure 12 displays an illustration of the sequence of operation of UFLS at an example UFLS relay (as presently operating within the network) with a frequency threshold of 49 Hz and a pickup time (time delay) of 100ms. The AMI arrangement would ideally aim to replicate this process.

The usual sequence of events after frequency crosses the nominated frequency threshold includes:

1. Frequency crosses the nominated threshold (in this case, 49Hz)
2. The relay allows at least 5 cycles (100ms) to measure frequency to avoid spurious triggering on transients
3. The relay may then wait for a further intentional time delay (e.g. 100ms)
4. The relay then operates a circuit breaker to disconnect load.

From system frequency crossing the UFLS frequency threshold (49Hz) to the opening of the breaker in this example there is a total delay of approximately 300ms. It is anticipated that AMI meters will need to replicate a similar process in similar timeframes to deliver an equivalent functionality.

Figure 12 Example of under-frequency power system event with UFLS operation (setting at 49 Hz)

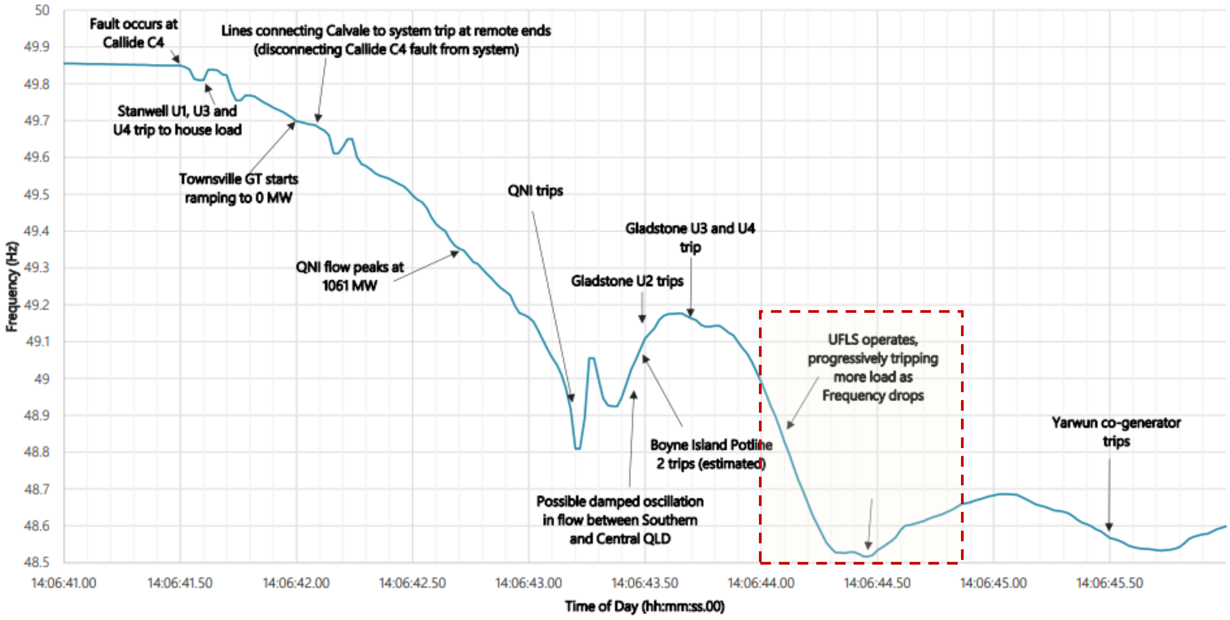


A1.3 Avoiding spurious tripping

Power system frequency in real events is typically "messy". For example, consider the frequency profile that occurred during the multiple contingency event on 25 May 2021[26], shown in Figure 13. In this event, the operation of UFLS once frequency fell below 49Hz successfully prevented system collapse.

[26] See final report at AEMO's website: https://aemo.com.au/-/media/files/electricity/nem/market_notices_and_events/power_system_incident_reports/2021/final-report-trip-of-multiple-generators-and-lines-in-qld-and-under-frequency-load-shedding.pdf?la=en

Figure 13 System frequency and major events during 25 May 2021 incident



Messy frequency profiles can also occur for milder events where UFLS relays should not operate and customer load should remain connected. It is essential that meters can "ride-through" short frequency transients and other milder disturbances, to avoid spurious tripping of customers. **It is expected that allowing a measurement time of at least 5-8 cycles (100-160ms) will be required to achieve this.**

The success of implementation of UFLS at the smart meter requires reliable operation if a severe under-frequency event occurs, as well as low to no levels of spurious or false tripping in milder events where customer tripping is not desired.

There are many different methods for measuring frequency. Understanding precisely how power system frequency is measured by the AMI devices will assist in understanding how likely it is that the smart meter will be able to ride through faults and various types of disturbances in the distribution network and keep customers connected.

Some examples of events that UFLS operation should ride through (ie. NOT disconnect customer load) include:

- Voltage sags
- Phase angle shifts
- Short frequency transients
- Network harmonics
- Voltage and reactive power oscillations

AMI manufacturers and DNSPs will likely need to conduct extensive testing of AMI products to demonstrate that they can perform the required capabilities and avoid spurious tripping for these types of events, and any other typical grid conditions.

A2. UFLS Responsibilities

This section summarises the allocation of responsibilities relating to emergency frequency control schemes (EFCS) and under frequency load shedding (UFLS), as per the National Electricity Rules (NER).

A2.1 AEMO's responsibilities

Under the general principles defined in the NER (4.2.6(c)), EFCS should be available and in service to:

- Restore the power system to a satisfactory operating state following protected events; and
- Significantly reduce the risk of cascading outages and major supply disruptions following significant multiple contingency events.

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 8.

Table 8 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(p1)	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 scheme.
4.4.2 (d)	AEMO must use reasonable endeavours to ensure that adequate facilities are available and under the direction of AEMO to allow the managed recovery of the satisfactory operating state of the power system.
4.3.1(v)	Initiate action plans to manage any significant deficiencies which could reasonably threaten power system security, including power system frequencies outside those specified in the definition of satisfactory operating state.

A2.2 NSP, JSSC and Market Customer responsibilities

The NER include a range of obligations and standards to be met by Network Service Providers (NSPs) and other registered participants, and supporting actions by Jurisdictional System Security Coordinators (JSSCs), to support the achievement of the power system security responsibilities relating to UFLS.

For reference, the key NSP, JSSC and market customer responsibilities supporting UFLS adequacy are set out in the following tables - NSPs in Table 9, JSSCs in Table 10, and market customers in Table 11.

Table 9 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	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. Transmission Network Service Providers and connected Distribution Network Service Providers must cooperate to agree arrangements to implement load shedding. The arrangements may include the opening of circuits in either a transmission network or distribution network. The Transmission Network Service Provider must specify, in the connection agreement, control and monitoring requirements to be provided by a Distribution Network Service Provider for load shedding facilities including emergency frequency control schemes.
S5.1.10.1a(a)	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 10 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 11 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.