Consumer Benefits of Improved Voltage Management

FINAL Project Report

Prepared for: The Australian Energy Regulator

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Executive Summary

This report details review of literature, research and data collection that has been undertaken to explore the range of possible consumer benefits that may accrue from improved management of supply voltage magnitudes. The project sought to answer following questions:

1. Is it possible to effectively identify and estimate the ways that overvoltage can impact consumers (e.g. through increased energy consumption)?
2. Are there practical and efficient solutions available to address these impacts from a distribution network perspective beyond what is already performed?
3. Are there practical ways in which distribution networks could consider these impacts in their investment decisions when considering existing network functions and regulatory obligations?
4. What further research may be needed to improve the way these impacts are assessed over time?

The review of literature undertaken for this project identified benefits for consumers through enhanced management of voltage magnitudes at or above the upper end of the allowable range and that recent implementation of lower cost strategies to decrease supply voltage magnitudes by distribution networks have been effective. However, the scale of these benefits is difficult to accurately quantify given that, into the future, distribution networks may need to implement higher cost solutions to reduce supply voltage magnitudes and that currently there are limits to accessing comprehensive, reliable data associated with calculating some consumer benefits.

Overall, the literature review identified that there is compelling evidence that supply at voltage magnitude above the nominal or rated voltage will lead to additional energy usage (and associated additional carbon emissions) as well as decreased appliance lifespan:

- When estimating the impact of supply at voltages above the nominal value, there appears to be sufficient data available to characterise the relationship between supply voltage magnitude and energy consumption for the devices which comprise the domestic load.
- When characterising the relationship between supply voltage magnitude and appliance loss of life, the available data is much more limited and is restricted to loss of life for incandescent lighting along with the electrolytic capacitors, with the latter being an integral component of switch mode power supplies.
- With respect to the impact of supply voltage magnitude on curtailment of consumer energy resources (CER). The evidence suggests that the economic impact is small at present and is unlikely to increase significantly over time.

The algorithms which have been developed in this report to estimate the impact of supply at voltage magnitudes above the nominal value in terms of both increased energy consumption as well as decreased appliance lifespan indicate the following:

- The consumer benefit of reducing voltages to closer to the nominal value of 230 V on energy consumption and in turn electricity bills is reasonably accurate and indicates benefits in the tens of dollars per dwelling per annum ongoing depending on the cost of energy used in the algorithm and the supply voltage magnitude.
- The consumer benefit of reducing voltages to closer to the nominal value of 230 V based on appliance loss of life is less reliable as it is based on limited data and specific consumer behaviours. A preliminary algorithm is provided to illustrate how estimates may be derived.

Given these limitations, a quantitative estimate of the consumer benefits of better management of supply voltage magnitudes as it applies to loss of life in consumer appliances has not been calculated in this report.

Further enhancements of supply voltage magnitudes are likely to require much higher cost solutions such as adjustment of network planning and operating strategies through to technology solutions, given that many of the low-cost solutions have now been implemented (including zone substation float voltage adjustment and distribution transformer tap position correction).

The options for Distribution Network Service Providers (DNSPs) to include voltage management initiatives beyond those related to CER hosting in regulatory submissions appears to be limited. To a reasonable extent, this is due to a lack of robust data which quantifies the relationship between supply voltage magnitude and impact on consumers. The inability of many DNSPs to access the data required to visualise network performance is also a limiting factor.

With respect to specific requirements for further research, the loss of life algorithm for electronic devices (and associated outputs), which as presented in this report is based on the performance of one component, requires refinement. This refinement can only be achieved through better understanding of the relationship between lifespan of whole devices (appliances) and supply voltage magnitude. Research tasks required for refinement of the algorithm include:

- Better understanding of the sensitivity of the full range of components (e.g. transformers and electronic switching components) that make up appliances to supply voltage magnitude.
- Better understanding of appliance turnover and failure rates.
- Better understanding of consumer sentiment to appliance replacement/renewal, i.e. if an appliance fails but a consumer is happy to replace it with a newer/upgraded model is the impact relevant?
- Better understanding of the relationship between supply voltage magnitude and loss of life for appliances that are predominately motor based.

Contents

1 Introduction

The Australian Energy Regulator (AER) commissioned the Australian Power Quality Research Centre (APQRC) at the University of Wollongong (UOW) to undertake research and data collection to explore the range of possible consumer benefits that may flow from improved management of supply voltage magnitudes including:

1. Reduced energy consumption;
2. Improved appliance lifespan;
3. Increased hosting capacity and reduced consumer energy resources (CER) curtailment;
4. Reduced CO_2 emissions due to 1. and 3.; and
5. Any other identified benefits.

The project seeks to answer the following questions:

1. Is it possible to effectively identify and estimate the ways that overvoltage can impact consumers (e.g. through increased energy consumption)?
2. Are there practical and efficient solutions available to address these impacts from a distribution network perspective beyond what is already performed?
3. Are there practical ways in which distribution networks could consider these impacts in their investment decisions when considering existing network functions and regulatory obligations?
4. What further research may be needed to improve the way these impacts are assessed over time?

The major tasks undertaken for the project are detailed below:

- **Establishment of a Jurisdictional Regulator Working Group -** The APQRC worked in conjunction with the AER to establish a jurisdictional regulator working group consisting of the appropriate personnel to provide an outline of voltage management practices within their jurisdiction and provide ongoing feedback on project deliverables.

- **Initial Findings Report** - This task involved development of a summary of key topics to be investigated in the project, specifically:
    - Identification of voltage management challenges.
    - Identification of probable inputs required to estimate the impacts of overvoltage.
    - Establish a brief of the varied voltage management approaches adopted by DNSPs in relation to compliance, incentives or managing network constraints.
    - Identification of the impacts of supply voltage magnitude on consumers.
    - A high-level assessment of methods of better managing voltage magnitudes and the practicality of their implementation.
    - A high-level summary of the existing evidence base.
    - Identification of gaps and overlaps with existing regulatory framework.

  The initial findings report was delivered in early May 2024.

- **Proposed Method to Estimate Impacts** - The focus of this task was to establish present state-of-the-art with respect to the impact of supply voltage magnitude on consumers. The task also identifies whether impacts can be sufficiently quantified based on existing research and evidence base. If an impact cannot be sufficiently quantified, then further evidence or research that would enable quantification will be identified. Once state-of-the-art was established a preliminary algorithm was developed to estimate the impact of supply voltage magnitude on consumers.

- **Assessment of the Challenges in Applying the Proposed Method** - This task assessed both the technical and non-technical challenges in applying the proposed impact estimation method. Emphasis has been placed on feedback from the AER, the jurisdictional working group and DNSPs.

- **High-level Estimates of Possible Net Benefits** - Using the algorithm developed, this task provides determination of the possible benefits of enhanced voltage management across the National Electricity Market (NEM). The task assessed key costs, data gaps and practical challenges in applying these methodologies and considered:
  1. Where situation-specific data may be accessible or cost-effectively gathered.
  2. Where system wide estimates may be practical or effective.
  3. Where increasing access to data across the system may impact these assessments.

In addition to the above activities, the following has also been completed:

- A survey of DNSPs was undertaken to better understand their position with respect to management of supply voltage in low voltage networks.
- A survey of Jurisdictional Regulators has been undertaken to better understand their position with respect to management of supply voltage in low voltage (LV) networks.
- A review of DNSP regulatory submissions has been undertaken to evaluate what aspect of supply voltage management that they consider require investment.

1.1 Structure of this Report

This report is a collation of all project tasks and is organised as follows:

- Section 2 provides a summary of the initial findings report which was delivered in early May 2024.
- Section 3 provides details of algorithms that can be used to estimate the consumer benefit of better management of supply voltage magnitudes. Algorithms have been developed to estimate benefits associated with reduction in energy consumption as well as increased appliance lifespan.
- Section 4 provides estimations of the benefits of better management of supply voltage magnitudes calculated using the algorithms described in Section 3.
- Section 5 provides discussion of the impacts of supply voltage magnitudes on curtailment of CER.
- Section 6 contains a description of a non-technical approaches to facilitating improved management of supply voltage magnitudes.
- Section 7 contains the outcomes of the survey of DNSPs.
- Section 8 contains the outcomes of the survey of Jurisdictional Regulators.
- Section 9 provides the review of DNSP regulatory submissions.
- Section 10 contains conclusions and recommendations.

2 Summary of Initial Findings Report

The Initial Findings Report [1] was delivered in early May 2024. This section provides a summary of the outcomes of that report which investigated the following topics:

- Identification of voltage management challenges in different regions;
- Identification of the impacts of supply voltage magnitude on consumers;
- A high-level assessment of methods of better managing voltage magnitudes and the practicality of their implementation;
- A high-level summary of the existing evidence base; and
- Identification of gaps and overlaps with existing regulatory frameworks.

A summary of the findings for each of the above is provided below.

2.1 Voltage Management Challenges in Different Regions

The most significant regional challenges for management of supply voltage magnitude were identified as the following:

- **Network load characteristics including energy supply fuel mix** – factors such as legacy planning processes/standards and traditional energy supply fuel mix, i.e. use of gas versus electricity, will have significant implications for management of supply voltage magnitudes as the electricity supply system transitions to higher levels of electrification and higher levels of CER integration.

- **Level of solar PV generation penetration** – solar PV generation will lead to some quantum of voltage rise which in turn can result in challenges for maintaining appropriate supply voltage magnitudes. The quantum of voltage rise is a function of both the amount of solar PV generation (i.e. penetration level) and the characteristics of the network (which are impacted by the factors detailed above).

- **Regulatory environment** – the regulatory environment in which a DNSP operates will influence the way in which it undertakes management of supply voltage magnitude. At present, there is a lack of consistency across jurisdictions in terms of technical standards, assessment and reporting requirements, and reward/penalty frameworks.

- **Access to data** - in some cases, the ability of DNSPs to manage supply voltage regulation, particularly in an environment of increasing CER, is hampered by a lack of access to data that enables visualisation and control of network performance. Traditionally, supply voltage magnitudes in low voltage (LV) networks were not considered to be of high importance. The limited information available was provided by relatively small numbers of power quality monitoring instrumentation. With integration of CER, voltage magnitudes in LV networks became much more visible to consumers, especially in relation to inverter disconnection due to overvoltage. While the roll out of smart metering devices has improved visibility of network performance, benefits have not accrued equally in all jurisdictions and lack of data remains a critical challenge for management of voltage.

2.2 Impacts of Supply Voltage Magnitude on Consumers

Steady state voltage magnitudes in low voltage networks have received increased exposure in recent years primarily due to consumers observing the behaviour (e.g. overvoltage disconnection) of inverters associated with CER as well as the increasing penetration of smart metering devices. While disconnection of inverters from the LV network due to overvoltage is highly visible, studies have shown that the actual economic impact from loss of solar PV generation is likely marginal for the average consumer [2]. Excluding impacts associated with curtailment of CER, the Initial Findings Report identifies that the main impacts of supply voltage magnitude on consumers manifests as the following:

(i) Variations in electricity bills due to relationships between supply voltage magnitude and appliance energy consumption; specifically, increased supply voltage magnitudes will result in increased electricity consumption and increased electricity bills; and
(ii) Accelerated aging and associated loss of life in consumer appliances when exposed to voltages above the rated value.

Given that a significant portion of electricity generation in Australia is still dependant on fossil fuels, the outcomes of (i) includes additional carbon emissions [3] associated with increased energy consumption.

2.3 Methods of Better Managing Voltage Magnitudes

The Initial Findings Report identified that there are many methods which can be used to regulate voltage magnitudes in low voltage networks. These methods range from network planning and operation functions, e.g. better configuration of zone substation float voltages and associated distribution transformer tap positions, through to network augmentation and technology solutions on both sides of the consumer meter. The Initial Findings Report provides an overview of the following methods for better managing voltage magnitudes:

- Network planning and operation
- Network upgrades
- Line capacitors
- Power factor correction
- Low voltage regulators
- Low voltage STATCOM
- On-load tap changing distribution transformer
- Ferroresonant (constant voltage) transformer
- CER inverter power quality response modes
- Energy storage
- Dynamic network operation
- Other technologies such as uninterruptible power supplies (UPS)

2.4 High-level Summary of the Existing Evidence Base

The Initial Findings Report identified that there is compelling evidence that supply of voltage above the nominal value will result in additional energy consumption and decreased appliance lifespan both of which manifest as costs to consumers. Other findings include:

- DNSPs are obliged to maintain voltage within prescribed limits and consumer appliances cannot be expected to operate efficiently and as intended outside these values. Assurance that, and if necessary, enforcement to ensure that voltage magnitudes are kept within technical limits should be a requirement for all DNSPs. While maintaining voltage magnitudes within technical limits must be the starting point, it is important to note that consumer impacts and benefits begin to accrue as soon as the supply voltage magnitude moves away from the nominal or rated voltage. Put another way, consumer benefits may be available even if supply voltage magnitudes are within the allowable voltage range.

- As the uptake of CER continues apace and as the transition to electrification of domestic dwellings proceeds in line with sector plans for decarbonisation, legacy network challenges will likely be exacerbated. This is particularly the case for networks which were not designed for significant electric space heating loads. This will tend to exacerbate existing challenges and may result in new problems.

- An additional aspect of electrification is that the number of electrical appliances will increase. This in turn increases the number of appliances which are reliant on an acceptable supply voltage magnitude environment and increases the quantum of any impacts of supply voltage magnitude on consumers.

2.5 Identification of Gaps and Overlaps with Existing Regulatory Frameworks

It was identified that there is some inconsistency in the technical requirements for supply voltage magnitudes across different state jurisdictions. It was also found that few jurisdictions (Victoria and to a lesser extent Western Australia) have active requirements in relation to reporting performance and/or frameworks to penalise/incentivise DNSPs to better manage supply voltage magnitudes in their networks.

3 Algorithm for Estimation of Economic Benefit of Improved Management of Supply Voltage Magnitude

As outlined in the Initial Findings Report, if impacts on CER are excluded, the impact of supply voltage magnitude on consumers manifests as increased energy consumption and decreased appliance lifespan. That being the case, the benefits to consumers of improved management of supply voltage magnitudes will accrue as reduced electricity bills and increased appliance lifespan manifesting as reduced replacement costs. Algorithms that could be applied to evaluate each of these aspects are detailed below. It should be noted that while the algorithms developed in this report are for residential dwellings, similar techniques could be applied for all load types.

The following assumptions are used for algorithm development:

- Performance at the nominal voltage, 230 V, is taken as the origin or zero value for all algorithm development. Consumer benefit accrues as the supply voltage is brought closer to 230 V.
- The algorithms only consider the benefits of reducing voltages above 230 V. This approach is justified as evidence to date suggests that the greatest impact on consumers is due to voltage magnitudes above the nominal, and all evidence suggests that Australian LV supply networks are characterised by voltage magnitudes at the upper end of the allowable range, with undervoltage concerns being limited to date.

3.1 Algorithm for Calculation of Benefits Related to Energy Consumption

There are a number of documents in the public domain that provide estimates for either additional energy consumption (in kWh) or economic impacts (in $) due to additional energy consumption or both. These documents are reviewed in Section 4.1.1. This section will focus on development of an algorithm that can be used to estimate the impact of supply voltage magnitude on energy consumption which in turn can be used to calculate the consumer benefit of better managing the supply voltage magnitude. The data required for the algorithm and the limitations of the algorithm are also discussed.

The proposed algorithm is predicated on development of a load model for an individual dwelling which can be scaled according to the identified impact of the supply voltage magnitude. This load model incorporates of the types of devices (appliances) as well as their usage patterns. Once a robust model for an individual dwelling has been developed it can be scaled by the number of dwellings to provide overall impacts, whether by region, state or nationally.

The initial findings report, as well as many other publications, have identified that the energy consumption of residential loads is dependent on the characteristics of each device which constitutes the load. For example, it is generally accepted that the energy consumption of electronic devices is not greatly impacted by supply voltage magnitude (i.e. electronic devices are a constant power and, in turn, a constant energy consumption load) while energy consumption for devices with motors will increase as supply voltage magnitude increases.

The proposed algorithm involves applying scaling factors for each load type to estimate the additional energy consumption, based on supply voltage magnitude. Figure 3-1 shows a high-level overview of the additional energy consumption algorithm.

Figure 3-1: High Level Overview of Additional Energy Consumption Algorithm

3.1.1 Residential Load Mix

Data from the residential baseline survey [4] commissioned by the Australian Federal Government can be used to provide an approximation of the mix of devices within a residential dwelling, based on the breakdown of energy consumption. The information in [4] is comprehensive with data provided on a year-by-year basis. For the purposes of demonstrating how the residential load mix can be estimated, data for 2023 for the state of Victoria has been utilised in this report. Victoria has been selected because supply voltage magnitude data is readily available due to the reporting requirements in the Victorian Electricity Distribution Code of Practice. The residential baseline survey breaks down devices in a residential dwelling into the following load categories:

- Appliances
- Cooking
- Lighting
- Space conditioning
- Water heating

Electricity consumption for transport (electric vehicles) is also included, however, at this stage the value is relatively small and has been excluded from this analysis. Of the above device categories, both theory and experimental evidence indicates that the energy consumption of the Appliance, Lighting and Space Conditioning categories is sensitive to supply voltage magnitude. For the Cooking and Water Heating devices, the quantum of energy required to achieve the desired outcome is effectively equal irrespective of supply voltage magnitude.

With respect to the Appliances category, the device mix is broken down into further categories. For the purposes of the algorithm being developed here, the devices can be categorised as either electronic or motor type. The Appliance device categories are listed below including indication of whether they have been identified as electronic or motor type:

- Clothes dryers (Motor)
- Clothes washers (Motor)
- Dishwashers (Motor)
- Freezers (Motor)
- Refrigerators (Motor)
- Computers – desktop (Electronic)
- Computers – laptop (Electronic)
- Game consoles (Electronic)
- Home entertainment - other (mostly audio equipment) (Electronic)
- Miscellaneous IT equipment (Electronic)
- Monitors (used with desktop computers) (Electronic)

- Set-top box - free-to-air (Electronic)
- Set-top box - subscription (Electronic)
- Television - composite average (Electronic)
- Video players and media recorders (Electronic)
- Wireless/Wired networked device (Electronic)
- Battery chargers (Electronic)
- Class 2 Common Areas (Electronic)
- Miscellaneous Pool Equipment – Elec (Motor)
- Pumps (Motor)

Limitation *– to some extent the categorisation of the devices presented above is simplified. Devices such as dryers, dishwashers and washing machines are composite loads consisting of both heating elements and motors which are present as pumps (as well as some electronics). The modern trend has also been for these appliances, plus refrigerators, to use an inverter, which is an electronic device, as an interface to the electricity supply. However, given the large stock of legacy devices which will be predominately simple motor devices the assumption that these appliances are of the motor type, while justified, will likely result in a slight over-estimation of impacts.*

Based on the above categorisations, and using residential baseline survey date, the appliance energy consumption is split 46%/54% Motor/Electronic.

With respect to the lighting load, devices are split into legacy (incandescent) lighting and high efficiency lighting (CFLs and LEDs). Based on these categories the residential baseline survey data indicates that the energy consumption for lighting is split 60%/40% legacy lighting/high efficiency lighting.

Using the above methodology, Figure 3-2 shows the breakdown of energy consumption in kWh by device category for Victoria for 2023 based on a total consumption of 1 kWh.

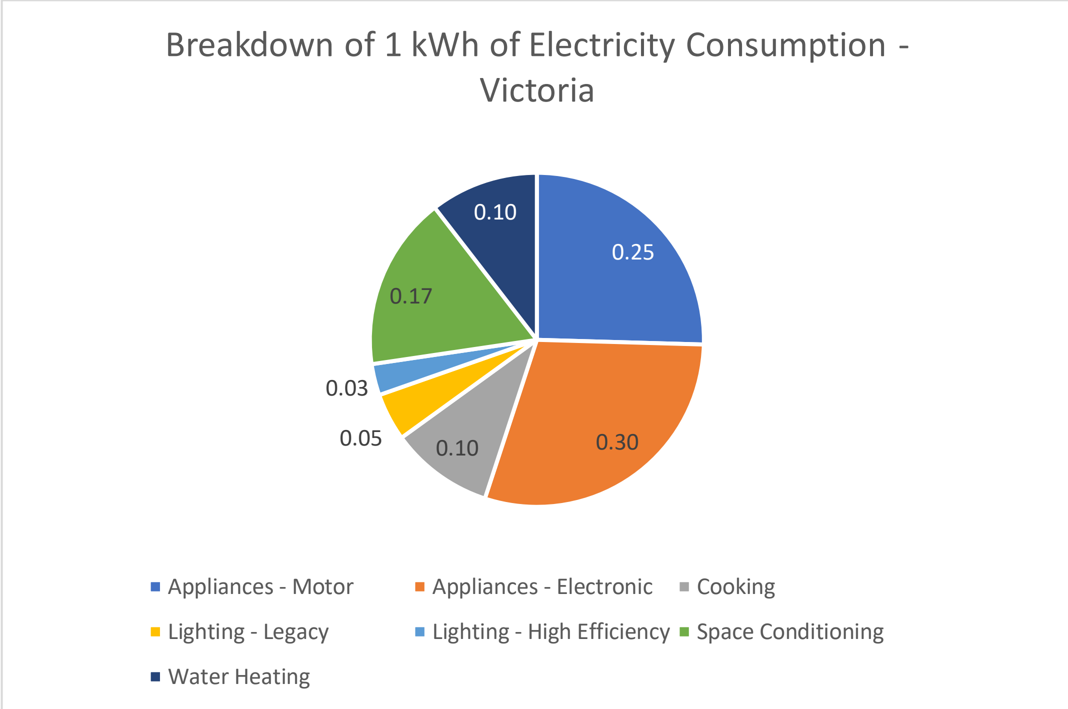

Figure 3-2: Breakdown of 1 kWh of Energy Consumption by Load category for Victoria for 2023

3.1.2 Energy Consumption Scaling

Using the data shown in Figure 3-2, it is possible to use load electricity consumption scaling factors to calculate the additional energy usage as supply voltage magnitude increases. As stated, the nominal voltage of 230 V is the origin (or zero value), and consumption increases as supply voltage magnitude increases. There are a range of scaling factors that could be adopted including published conservation voltage reduction (CVR) values. For the purposes of this report, the simplified values shown in Figure 3-3, which is drawn from [5], are utilised.

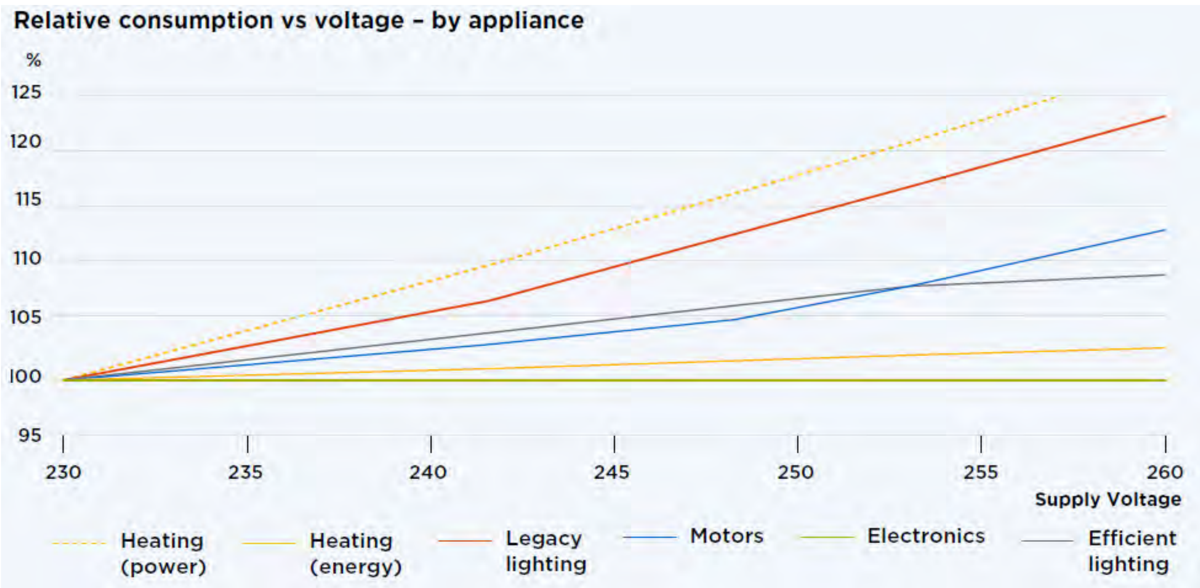

Figure 3-3: Energy Consumption versus Voltage for Different Load Types from [5]

Using the above information, it is possible to scale energy consumption based on load mix and supply voltage magnitude. The simple equation for this calculation is as follows:

$$Energy\ consumption\ \times Scaling\ factor = Scaled\ energy\ consumption \qquad (1)$$

***Limitation** – the above calculations require knowledge of the supply voltage magnitudes within electricity supply networks. This data is much more readily available to some DNSPs (e.g. Victoria) than others.*

3.2 Algorithm for Calculation of Benefits Related to Loss of Appliance Lifespan

While there is a strong theoretical basis and considerable published literature to support the relationship between supply voltage magnitude and energy consumption, this is not the case for the impacts of supply voltage magnitude on consumer appliance lifespan. To estimate the impact of supply voltage magnitude on consumer appliance lifespan and in turn calculate the potential consumer benefit, it is necessary to understand the relationship between supply voltage magnitude and appliance life to estimate the accelerated depreciation caused by supply at voltage magnitudes above the nominal (rated) value. The impact of supply voltage on appliance lifespan will vary depending on the characteristic of the load. For the purposes of this report, residential loads can be categorised as electronic, motor, or legacy (incandescent) lighting. With respect to incandescent lighting, there are well established relationships between the lamp life and the supply voltage magnitude, allowing easy development of a loss of life algorithm. For electronic loads, limited data is available which relates the lifespan of capacitors to supply voltage magnitude. However, electronic devices include many other components for which no quantitative data relating supply voltage magnitude to appliance lifespan is available. For the motor device type, although the Initial Findings Report was able to identify multiple qualitative sources which state that lifespan will be reduced as supply voltage magnitude increases, no quantitative data exists. As such, it is not possible to develop an accelerated depreciation algorithm for motor type loads and this remains an area requiring further research (see Section 4.3.3). Considering these factors, an accelerated depreciation algorithm has been developed for two device types:

- Incandescent lighting equipment: where the algorithm is predicated on well-known relationships between supply voltage magnitude and lamp lifespan.
- Electronic equipment: where the algorithm is predicated on the relationship between supply voltage magnitude and the lifespan of electrolytic capacitors which are used in the front end of switch mode power supplies. Given that this algorithm only includes evaluation based on performance of a single component, the algorithm must be considered to be preliminary and is provided to illustrate an application as opposed to quantitative values.

Similar to the case for the energy consumption algorithm, the loss of appliance life algorithm is predicated on development of a load model for an individual dwelling which can then be scaled according to the identified impact of the supply voltage magnitude on appliance life. Once a robust model for an individual dwelling has been developed it can be scaled by the number of dwellings to provide overall impacts whether by region, state or nationally.

The following data is required for the algorithms:

- A nominal purchase price for each appliance.
- A nominal rated lifespan for each device. This is used to determine the ‘rated’ depreciation cost per annum for each device type. The model then uses accelerated aging curves or

equations which provide the relationship between supply voltage magnitude and loss of life to calculate accelerated depreciation costs.
- The number of each device in each dwelling.
- The magnitude of the supply voltage.

In simple terms, the algorithms scale the device lifespan according to the relationship between lifespan and supply voltage magnitude to evaluate the voltage dependent loss of life. Using the data provided above, the rated depreciation for each dwelling is calculated as follows:

$$Rated\ Depreciaiton = \frac{Number\ of\ Devices\ Per\ Dwelling \times Purchase\ Price\ Per\ Deivce}{Rated\ Lifespan} \quad (2)$$

This rated depreciation can then be compared to a rerated depreciation based on loss of life calculations. The cost impact is then calculated as:

$$Loss\ of\ Life\ Cost = Rerated\ Depreciation - Rated\ Depreciation \quad (3)$$

The units for the above equation are $ per annum.

3.2.1 Incandescent Lighting Accelerated Depreciation Model

This model calculates the accelerated depreciation for incandescent lighting equipment. The relationship between supply voltage magnitude and incandescent lighting lifespan is relatively well-known and is expressed by the equation from [6]:

$$Rerated\ Life = \left(\frac{V_a}{V_d}\right)^{-12\ to -16} \times Life\ at\ Rated\ Voltage \quad (4)$$

Where

- V_a is supply voltage magnitude
- V_d is design (rated) voltage magnitude (assumed to be 230 V)

For traditional incandescent lamps the exponent in the above equation is -16, while for halogen lamps the exponent is -14.

3.2.2 Electronic Load Accelerated Depreciation Model

The accelerated depreciation model for electronic loads is based on experimental results for electrolytic capacitors obtained by the University of Wollongong and published in [7]. The relationship between supply voltage magnitude and accelerated aging of electrolytic capacitors is given by the blue trace in Figure 3-4.

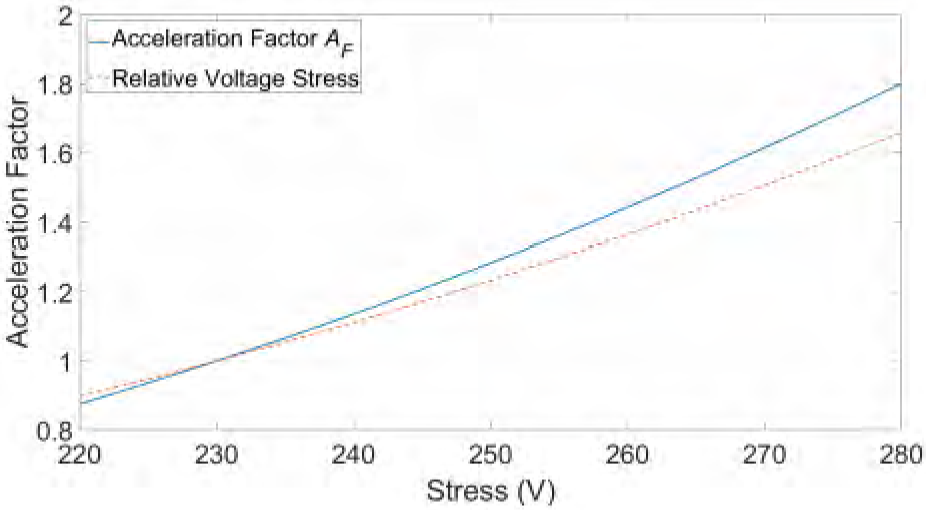

Figure 3-4: Relationship between Supply Voltage Magnitude and Loss of Life Acceleration Factor [7]

A linear equivalent has been calculated for blue trace shown in Figure 3-4 and is given by:

$$Acceleration\ Factor = 0.0125 \times Supply\ Voltage\ Magnitude - 1.875 \qquad (5)$$

Using the above relationship between supply voltage magnitude and loss of life acceleration factor, an accelerated depreciation value can be obtained using the same methodology as is applied for incandescent lighting devices.

***Limitation** – This electronic loss of life algorithm is based on a single component of electronic devices, the electrolytic capacitor which forms the DC bus of switch mode power supplies (SMPS). The model is predicated on all electronic devices incorporating a capacitor with similar characteristics. While there is peer reviewed scientific evidence to suggest that this capacitor is likely the component most sensitive to supply voltage magnitude, actual electronic devices contain a multitude of other components each of which will have their own relationships between lifespan and supply voltage magnitude. As such, this methodology is incomplete at the present time and requires further research to provide additional data.*

4 Estimation of Benefits

4.1 Energy Consumption

4.1.1 Published Data

There are a number of studies that estimate for impact of supply voltage magnitude on energy consumption in the public domain. The study presented in [8] developed two household load models to estimate the additional costs associated with increasing supply magnitude away from the 230 V nominal. The characteristics of each of the households are shown in Table 4-1. The study used measured CVR factors and an estimated appliance type and usage mix to produce the values shown in Figure 4-1.

Table 4-1: Household Model Characteristics [8]

	Household A	Household B
Type	Standalone House	Standalone House
No. Occupants	4	2
Floor Area	200 m^2	160 m^2
Energy Consumption	9000 kWh/yr	6500 kWh/yr
Hot Water Heater	Natural Gas	Electric
Other	Pool	-

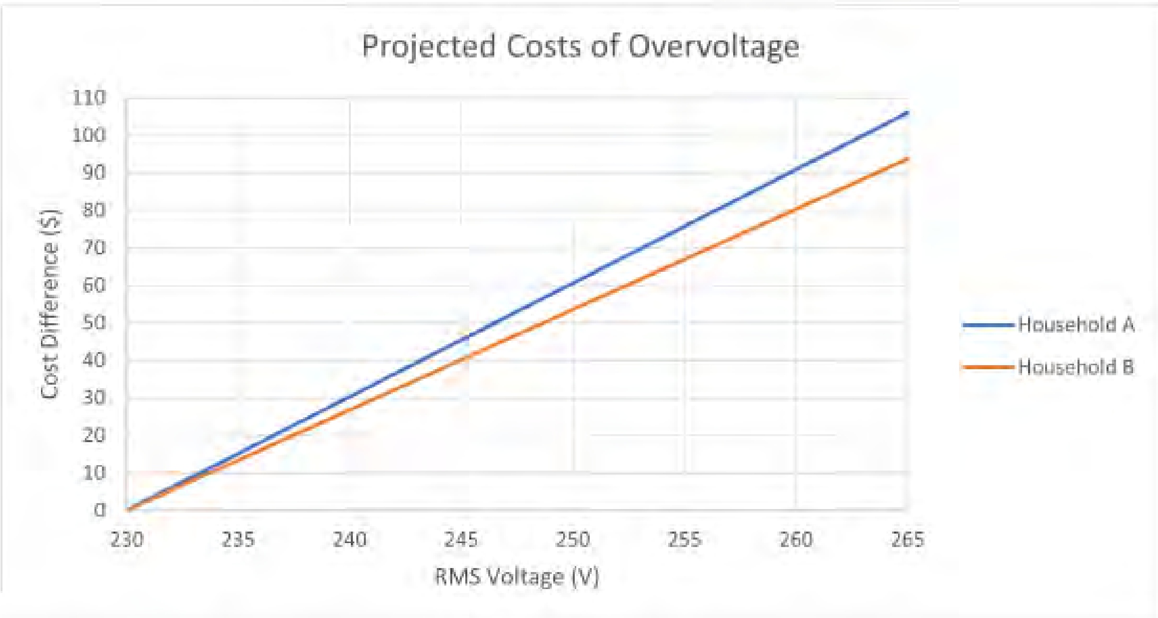

Figure 4-1: Projected Additional Costs based on Supply Voltage Magnitude [8]

In [5] it is stated:

"Analysis commissioned by DELWP based on data published by Victorian distribution businesses in line with EDCoP reporting obligations estimated that voltages higher than 230 volts in Victoria resulted in 237 gigawatt hours of increased electricity consumption and 12,206 kilotons of carbon emissions per year. 12,206 kilotons of carbon emissions per year is the equivalent of taking 62,000 internal combustion engine cars off the road every year in Victoria."

Another Victorian DEECA publication [9] states:

“it is estimated that a typical customer will expect to see a 0.1% increase in energy for every one volt above 230 volts, and 0.13% per volt above 253 volts.”

4.1.2 Algorithm Output

This section presents examples of application of the algorithm described in Section 3.1 in order to quantify the energy consumption related benefits to consumers of better management of supply voltage magnitudes.

As an introduction, consider a single household using a fixed average supply voltage magnitude. For the purposes of this example, a supply voltage magnitude of 242 V has been selected. This value is in line with the data for average Victorian DNSP voltage magnitudes given in [5]. Based on this average voltage magnitude, estimates of the energy consumption scaling factors for the various load categories shown in Figure 3-3 are given in Table 4-2.

Table 4-2: Energy Consumption Scaling Factors for 242 V

Load Category	Scaling Factor
Heating (energy)	1.01
Legacy Lighting	1.07
Motors	1.07
Electronics	1
Efficient Lighting	1.08

Using legacy lighting as an example, if equation (1) is applied using the data shown in Figure 3-2 and Table 4-2, the scaled energy consumption for Legacy Lighting for a supply voltage magnitude of 242 V is:

$$Scaled\ energy\ consumption = 1.07\ \times 0.05 = 0.0535 \text{ kWh}$$

The above calculation shows that for legacy lighting, supply at 242 V will add an additional 0.0035 kWh to each 1 kWh of consumption compared to the value at 230 V.

If this technique is applied across all load types based on data for 2023, it is estimated that a dwelling will consume 1.025 kWh at 242 V for each kWh at 230 V. Average daily electricity consumption per dwelling in Victoria is of the order of 12.6 kWh [10]. If this is taken as the consumption value at 230 V, supply at 242 V will result in consumption increasing to 12.92 kWh or an additional 0.32 kWh per day. This equates to an additional 115 kWh per annum.

Using the above process, Figure 4-2 shows an estimation of the additional energy consumption per dwelling by supply voltage magnitude for Victoria using a 1 kWh base. To interpret the data shown in Figure 4-2, consider the example of 255 V. Here it can be seen that a consumer supplied at 255 V will consume approximately 1.1 kWh compared to the 1 kWh that would be consumed by a consumer supplied at 230 V. Hence the benefit of reducing the voltage to the consumer supplied at 255 V is 0.1 kWh for every kWh consumed. An alternate view of the data shown in Figure 4-2 is presented in Figure 4-3 which shows relationship between increased energy consumption and supply voltage magnitude as a percentage. If energy costs are known, then the data shown in Figure 4-2 and Figure 4-3 can be applied to determine the overall economic impacts on consumers. A case study indicating an approach to quantifying additional energy costs to consumers based on supply voltage magnitude is presented in Appendix A.

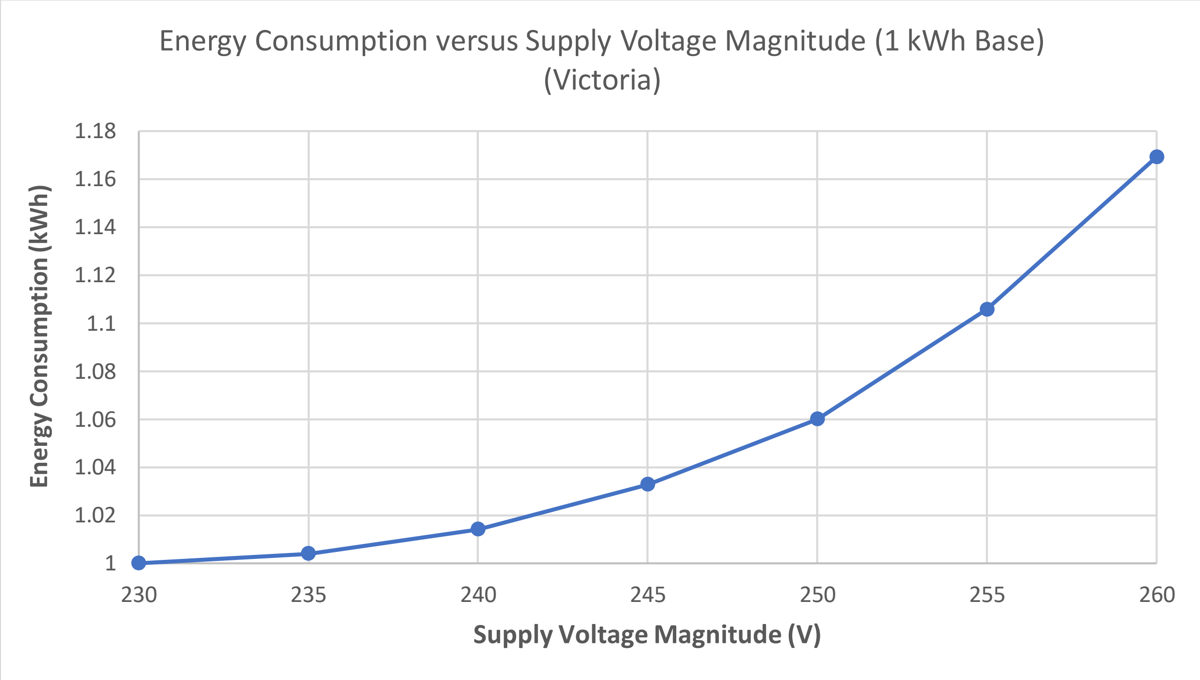

Figure 4-2: Relationship between Supply Voltage Magnitude and Energy Consumption per kWh (for Victoria for 2023)

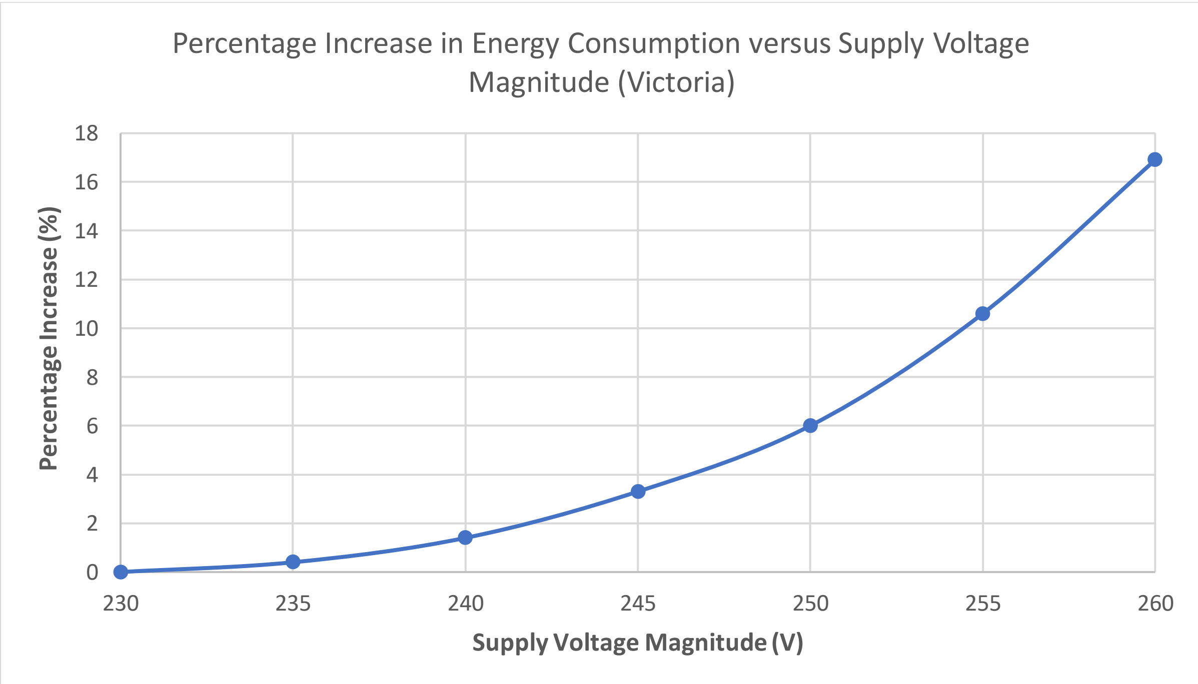

Figure 4-3:Relationship between Supply Voltage Magnitude and Percentage Increase in Energy Consumption (for Victoria for 2023)

Note – The outputs detailed above are based on an average value of energy consumption per dwelling. The algorithm, and in turn the outputs, could be refined by calculating values on a periodic basis across the day if sufficient supply voltage magnitude and consumer load mix data is available.

4.2 Appliance Lifespan

This section presents examples of application of the algorithm described in Section 3.2 in order to quantify the appliance lifespan related benefits to consumers of better management of supply voltage magnitudes. The limitations of the algorithm are also detailed.

4.2.1 Incandescent Lighting

Based on the algorithm presented in Section 3.2.1, Figure 4-4 and Figure 4-5 show the relationship between supply voltage magnitude and halogen lamp and incandescent lamp lifespan respectively. The significant decrease in lifespan as supply voltage magnitude increases is readily apparent. In both cases, lamp lifespan is approximately halved when supply voltage magnitude reaches approximately 242 V (based on a rated voltage of 230 V). In other words, consumers supplied at 242 V will be replacing incandescent lighting devices at twice the rate of consumer supplied at 230 V. consumers supplied at 254 V will be replacing devices at 4 times the rate of those supplied at 230 V.

This data can be combined with the numbers of devices per dwelling as well as the cost of the devices to provide quantitative economic impacts. A case study showing an approach for these calculations is given in Appendix B.

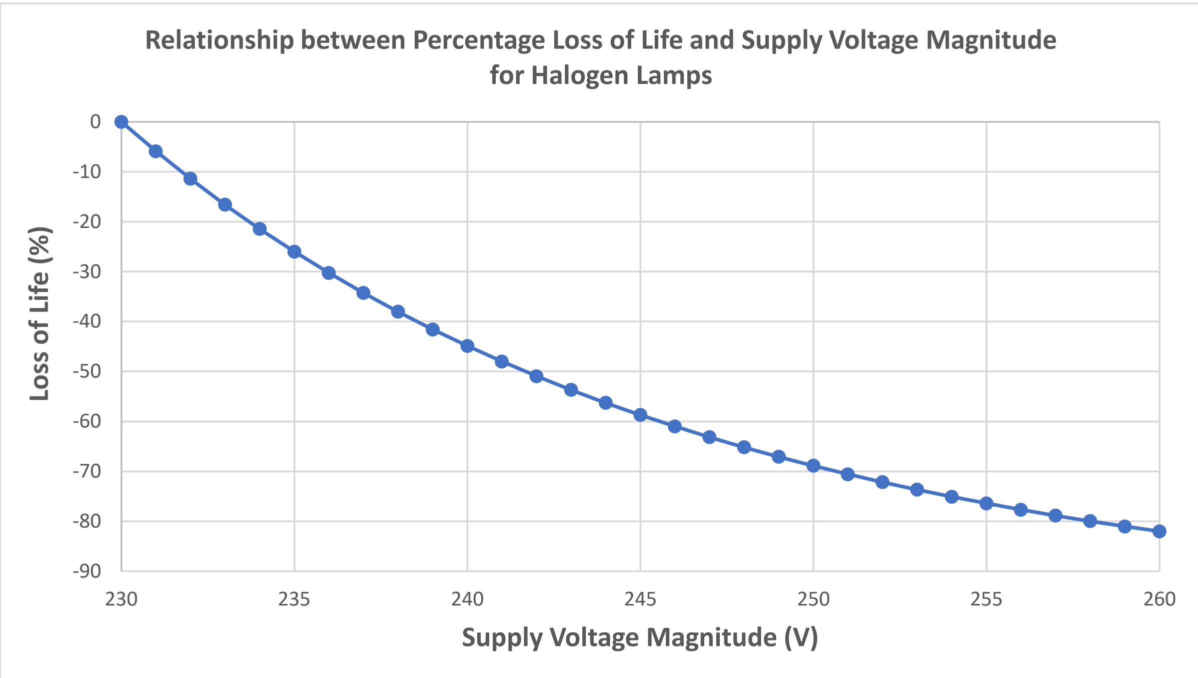

Figure 4-4: Relationship between Percentage Loss of Life and Supply Voltage Magnitude for Halogen Lamps

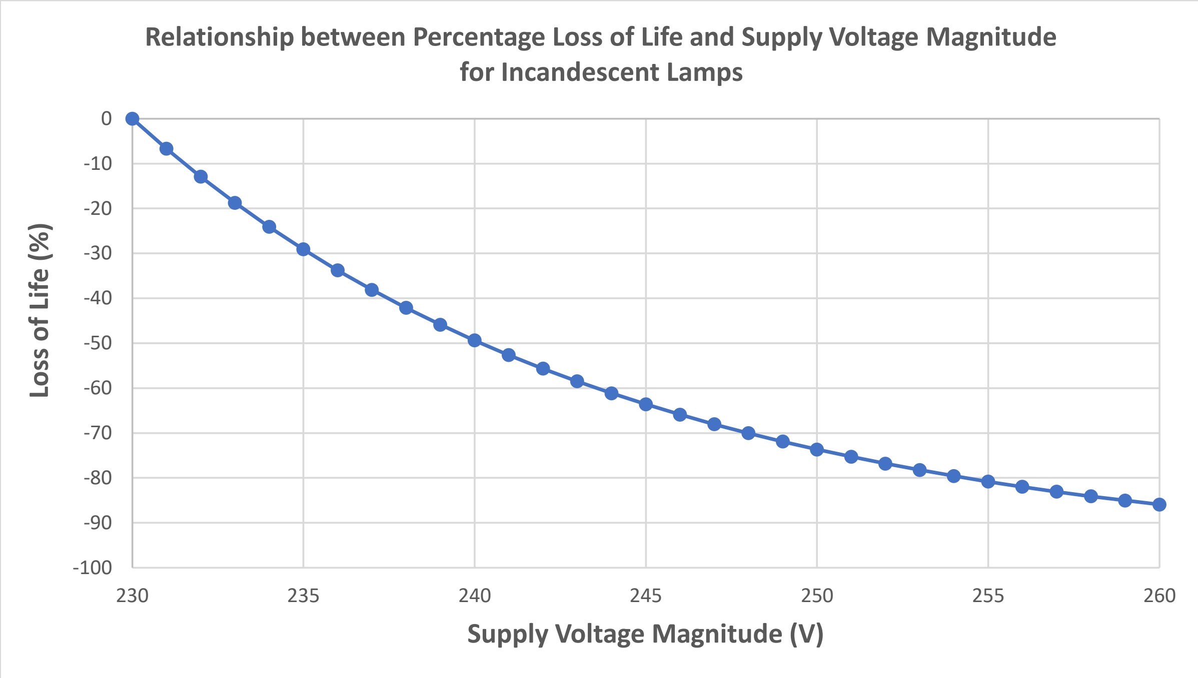

Figure 4-5: Relationship between Percentage Loss of Life and Supply Voltage Magnitude for Incandescent Lamps

4.2.2 Electronic Devices

Based on the algorithm presented in Section 3.2.2, Figure 4-6 shows the relationship between supply voltage magnitude and the lifespan of the capacitors used in many consumer electronic devices. The decrease in lifespan as supply voltage magnitude increases is clear. Devices supplied at 240 V will suffer a reduction in lifespan of 12.5% while those supplied at 250 V will suffer a lifespan reduction of 25%.

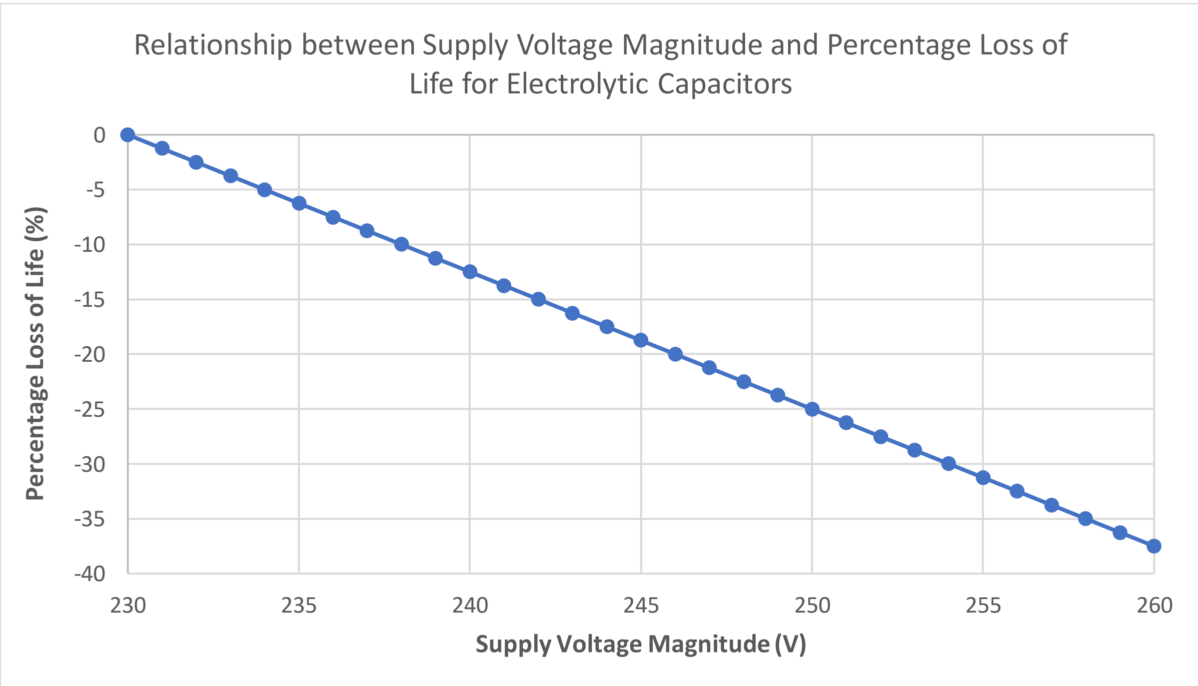

Figure 4-6: Relationship between Supply Voltage Magnitude and Loss of Life for Electrolytic Capacitors

4.3 Algorithm Limitations and Refinements

This section provides discussion on the limitations of the algorithms and outputs provided in this report and also provides details of how the algorithms could be refined.

4.3.1 Load Mix

The calculation which determines the load mix for the additional energy consumption algorithm is based on energy consumption data from the residential baseline survey. To some extent these energy consumption figures already include the impacts of supply voltage magnitude which may skew the device mix.

4.3.2 Voltage Magnitudes

Each of the algorithms requires supply voltage magnitude data as an input. Access to supply voltage magnitude data is much more readily available to some DNSPs than others.

4.3.3 Device Characteristics

As noted in the relevant sections, in some cases, there is insufficient data to evaluate the impact of supply voltage magnitude on some consumer devices. In particular:

- No quantitative relationship can be established between supply voltage magnitude and loss of life for devices containing motors.
- The loss of life algorithm for electronic loads is incomplete as it only includes performance for electrolytic capacitors.

Given the above, the loss of life model presented in this report is incomplete. Development of a comprehensive model requires further research to establish relationships between supply voltage magnitude and the lifespan of devices which contain motors and complex electronic loads.

4.3.4 Lack of Appliance Failure Data

One of the limitations of the loss of life model for electronic loads is a lack of verifiable data with respect to both failure rates and failure modes for electronic devices that could be used to verify theoretical qualitative findings. The authors are aware that the Federal Government may have access to data of this nature, however, it is not in the public domain.

Another limitation of the loss of life model is that it assumes that consumers are concerned with the whole costs of replacement of a failed device. It can reasonably be assumed that in some cases a consumer may view the failure of a device as an opportunity to upgrade to a newer or superior model. In this case the cost impact borne by the consumer may not be of significant concern to them.

4.3.5 Risks Associated with Undervoltage

This report has focused on the consumer benefits that may be achieved by reducing supply voltage magnitude. While there is compelling evidence that demonstrates that voltage reduction will benefit consumers, it should be noted that wide scale reduction of supply voltage magnitudes will likely result in an increase in instances of supply voltage magnitudes being at the lower end of the allowable range (or possibly below). While both theory and testing have indicated that the majority of domestic loads will operate as expected down to voltage magnitudes of 200 V, the following are some of the risks associated with operating networks at lower voltage magnitudes:

- Some devices may not operate as expected. The primary concern here is for devices with motors, where heavily loaded motors may not have the torque to start or could stall. This concern may be more relevant in industrial/commercial situations as opposed to residential dwellings.
- Some undervoltage protection systems may operate if they have not been configured correctly.
- Increases in current can be expected due to the characteristics of constant power loads (where current increases as voltage decreases). It is possible that this additional current may lead to thermal capacity constraints.
- The output of some devices will decrease. This includes:
    - Reduced light output from incandescent lighting sources.
    - Water heating, including kettles, will take longer.
    - Devices with simple elements (e.g. toasters, heaters) will have reduced output and will take longer to perform tasks (e.g. toast will take longer to cook).
- Tolerance to voltage sags may be reduced as there will be less stored energy in elements such as capacitors.

4.3.6 Estimates of Appliance Value and Lifespan

The loss of life algorithms requires estimates of both appliance initial cost (purchase price) and lifespan. The more accurate this input data, the more accurate the output values of algorithms will be.

4.3.7 Algorithm Refinements

The estimates provided in this report are based on averages and for single points in time. With sufficient data it should be possible to estimate the benefits for each individual dwelling at any given point in time. The data required includes time varying supply voltage magnitude data as well as the time varying device mix for each individual dwelling. A further enhancement for the additional energy consumption model involves using actual CVR factors for each device. This model would be highly accurate for each dwelling but require a significant amount of input data.

The algorithms also provide benefits which are assessed based on the ability to supply all locations at 230 V. Both the physics and the cost-effective design of electricity supply networks precludes supply at 230 V at all locations. There will always be locations where the supply voltage magnitude must be higher while there will be others where the supply voltage magnitude will be lower. As such, the estimates provided in this report may need to be adjusted to better reflect the actual capabilities of electricity supply networks which in turn may require additional supply voltage data (see Section 4.3.2).

5 Impacts of Supply Voltage Magnitude on Consumer Energy Resources

This section provides some discussion of the impact of supply voltage magnitude on the operation of CER with the primary focus being on impacts associated with curtailment of solar PV export. The impact of supply voltage magnitude on lifespan of CER inverters can be assessed using the electronic loss of life models detailed in Section 3.2.2.

AS/NZS 4777 Part 2 [11] prescribes inverter operating limits for both short term and sustained supply voltage magnitude. The short-term overvoltage limits are effectively protection settings, which are a response to abnormal network operating conditions including loss of grid (islanding). The short-term overvoltage limits of 265 V and 275 V are significantly higher than any supply voltage magnitude likely to be observed in low voltage networks under normal operating conditions and as such are not given further consideration.

With respect to sustained operating voltage, inverters must disconnect if the 10-minute average voltage exceeds 258 V. While inverters must disconnect if the sustained operating voltage exceeds 258 V, Volt-Watt and to a lesser extent Volt-VAr response modes (which are mandatory and must be enabled by default) will likely see curtailment commence at a value below this limit. The Volt-Watt response mode varies the output active power depending on the voltage at the inverter terminals. While the Volt-VAr response mode varies the reactive power injected or absorbed by the inverter based on the voltage magnitude at the inverter terminals. An example of a Volt-Watt response droop curve is shown in Figure 5-1. As can be seen, the inverter progressively lowers the active power (Watt) output as the voltage exceeds the pick-up voltage threshold, resulting in the inverter injecting reduced active power as the voltage magnitude increases. The values of V_{w1} and V_{w2} are prescribed by the network operator. As an example, the power levels (with respect to rated power) may be 100% at V_{w1} and 20% at V_{w2} with V_{w1} being 253 V and V_{w2} being 260 V (in a 230 V nominal network).

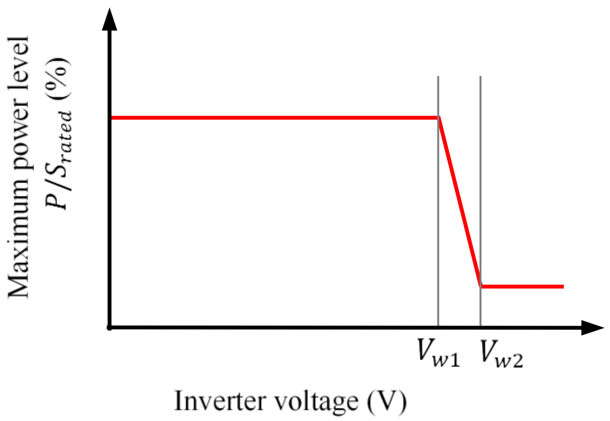

Figure 5-1: Example Volt-Watt Response Droop Curve [11]

An example of a Volt-VAr response droop curve is shown in Figure 5-2. In this response mode, the inverter is required to inject reactive power when voltage magnitudes are low and absorb reactive power when voltage magnitudes are high. Default values for the voltage values for the majority of Australia are as follows:

- V_{V1}: 207
- V_{V2}: 220
- V_{V3}: 240

- V_{V4}: 258

The requirement for injection or absorption of reactive power will reduce the total amount of active power that can be exported by the inverter thus curtailing output. However, the relationship between inverter rating and active and reactive power quantities means that the magnitude of curtailment of active power due to operation of Volt-VAr response will generally be lower than that for Volt-Watt response.

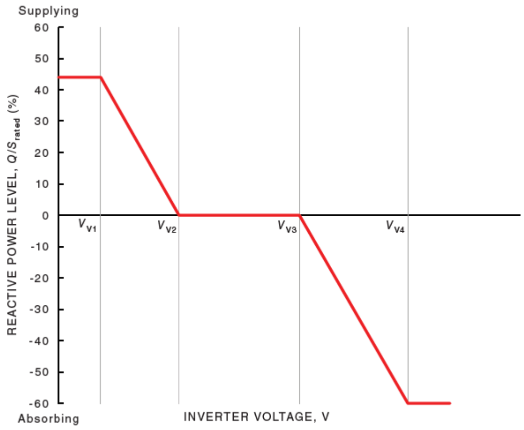

Figure 5-2: Example Volt-Var Response Droop Curve [11]

5.1 Regulatory Environment

In August 2012, the Australian Energy Market Commission (AEMC) published changes to the National Electricity Rules (NER) and National Energy Retail Rules (NERR) which aim to integrate distributed energy resources (DER) more efficiently into the electricity grid. The rule change required the AER to develop Customer Export Curtailment Values (CECV) which are designed to help guide efficient levels of network expenditure for the provision of export services and serve as an input into network planning, investment and incentive arrangements for export services. The rule change also requires distribution businesses to plan for the provision of export services and strengthens customer protections and regulatory oversight by the AER. CECV values are a critical input to the methodologies that should be used by DNSPs to establish the Value of Distributed Energy Resources (VaDER) figures which are used to justify expenditure in regulatory proposals. While not a direct measure of the impact of curtailment on consumers both CECV and VaDER provide insights into the value of solar PV export and conversely the impact of curtailment.

5.2 Empirical Evidence

5.2.1 University of NSW Study

In 2020, the Energy Security Board commissioned the Centre for Energy and Environmental Markets at the University of New South Wales to undertake analysis of voltage on the LV networks within the NEM, as well as the influence of distributed PV generation on that voltage [2]. While the study identified prevalence of supply voltage magnitudes at or above the allowable range, the study indicated that the actual economic impact on consumers resulting from loss of feed-in tariff revenue due to solar PV generation curtailment is low on average. As stated in the report:

"*analysis indicates that overall curtailment over these sample days is low with an average of around 1% generation loss over the study period for all sites (including those which experienced zero curtailment losses). Upscaling the estimated generation loss to all of South Australia finds a total lost 'curtailment' value of $0.8m - $2.6m per year assuming that the sample is representative of all sites, and that the twenty-four clear sky days are representative of all days throughout the year. The use of clear sky days in particular is likely to result in an over-estimation of curtailment, and all findings are subject to key method limitations.*" [2].

5.2.2 CECV Values

The latest CECV values by jurisdiction are shown in Figure 5-3 which illustrates:

- The annual average time-weighted CECV (blue trace)
- A rooftop-PV output-weighted CECV (average of the CECV in all periods of rooftop PV electricity generation) (yellow trace)
- The average CECV during periods of very high roof-top PV electricity generation (half-hour periods in which rooftop PV production is in the top 1%, which is when curtailment is assumed to be most likely to occur) (orange trace)

Figure 5-3 clearly indicates that the CECV values are predicted to be low for scenarios which involve significant levels of solar PV penetration. In the Key Drivers of Changes in 2024-25 CECVs - 2024-25 CECV Update [3] it is stated that:

"… *CECVs at those times when rooftop PV output is at its highest (the Top 1% RfPV scenario) decrease rapidly and substantially (approaching zero) in all jurisdictions, due to increased rooftop and large-scale solar penetration exerting downward pressure on mid-day prices.*" [3].

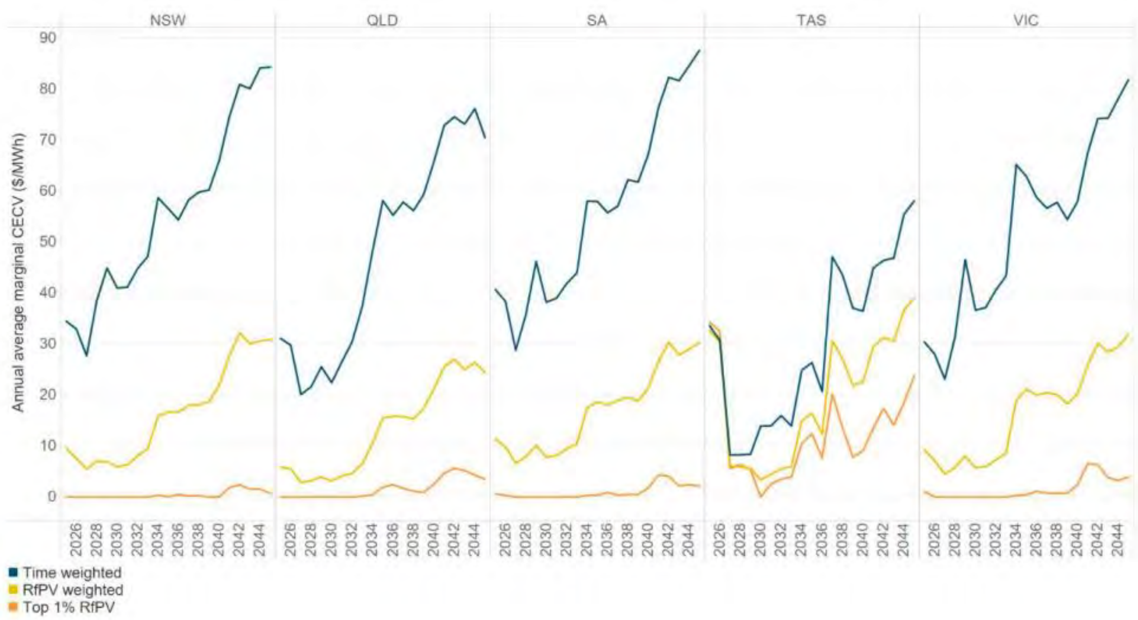

Figure 5-3: CECV Values by Jurisdiction over the Analysis Period [3]

5.3 Summary

There are a number of factors that suggest that the economic impact associated with curtailment of CER due to supply voltage magnitude is likely to be relatively small on average, decreasing, and considerably smaller than the impacts associated with increased energy consumption and appliance loss of life. The factors include:

- Solar PV generation feed-in tariffs are decreasing and a number of DNSPs are beginning to implement network charges for solar PV exports. As such, the value of exports is decreasing over time. Consequently, the impact associated with inability to export is also decreasing.
- CECV values are low to very low for scenarios which involve high levels of solar PV generation.
- Regulatory proposals indicate that expenditure on CER related activities will be modest in the short to medium term. For example, the Endeavour Energy regulatory proposal for 2024 – 2029 contains provision for $9 million per annum [12] for all aspects of DER integration. Even if all of this expenditure was for voltage management (which it is not), given that Endeavour Energy has over 1 million customers, expenditure is only $9 per customer per annum.
- In most situations solar PV generation curtailment will only commence once the voltage magnitude at the inverter terminals exceeds 253 V. Given the 2% allowance for voltage rise between the point of supply and the inverter terminals, curtailment may commence when the supply voltage magnitude reaches 251 V at the point of supply. The vast majority of DNSPs have been actively working to reduce supply voltage magnitudes meaning that the number of instances of supply voltage magnitudes exceeding these levels is likely to reduce over time which in turn will result in reduced curtailment.
- In addition to the dot point above, updates to the NER allow for DNSPs to develop specific strategies using CECV and VaDER values that are included in regulatory proposals. These activities will result in better management of supply voltage magnitude and in turn reduced curtailment.

6 Non-Technical Methods for Enhancing Management of Supply Voltage Magnitudes

Experience in Victoria indicates that requirements for public reporting of supply voltage magnitude performance can be a compelling motivator for DNSPs to take action to better manage supply voltage performance in order to avoid reputational damage. When the Victorian Electricity Distribution Code of Practice (EDCoP) was updated to Version 11 in 2020, it included requirements for voltage performance reporting which apply to all Victorian DNSPs. These reporting requirements have subsequently been refined in latter versions of the code.

In addition to the EDCoP data reporting requirements, the Essential Services Commission (ESC), Victoria's energy regulator, has introduced new voltage performance reporting indicators for distributors under the Compliance and Performance Reporting Guideline. From 1 March 2022, the new performance indicators require distributors to report to the ESC quarterly on the percentage of customers per week whose voltage performance fell outside of the allowed soft and hard voltage limits.

While voltage performance reporting requirements were included in the Code of Practice, little was done with the data and little impact was observed until the then regulator, the Department of Energy, Water, Lands and Planning (DELWP – now Department of Energy, Environment and Climate Action (DEECA)) began a range of advocacy activities with DNSPs ostensibly related to CER hosting capacity. A timeline of these activities and the impact that they had on supply voltage magnitudes is shown in Figure 6-1. A clear downward trend in voltage magnitudes is observed especially after June 2021 when DEECA began direct engagement with DNSPs.

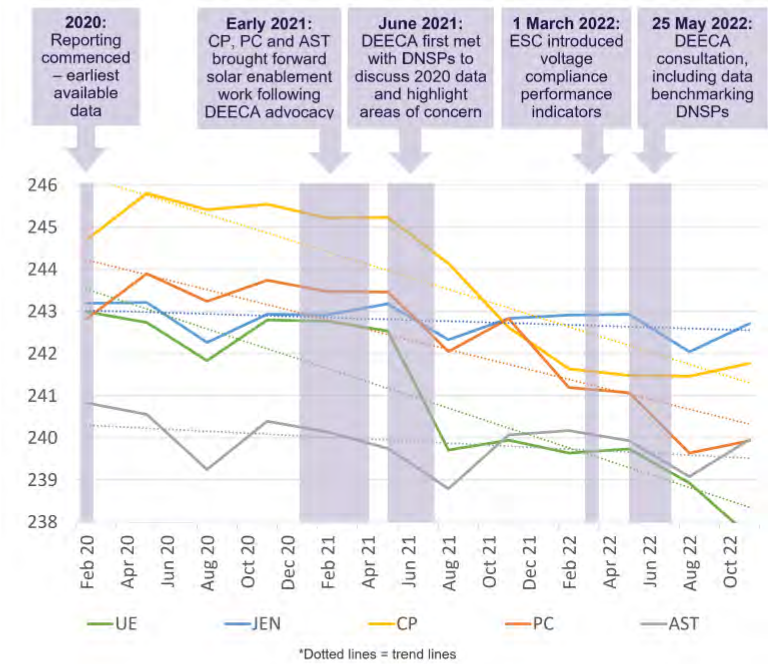

Figure 6-1: Average voltage by Distribution Network Service Provider (DNSP) from 2020 to 2022, and key Victorian Government actions from [9]

The limitation of the approach taken in Victoria is that it requires the DNSPs to have access to sufficient supply voltage management data either from their own network monitoring infrastructure or by access to data from smart metering devices. In general, DNSPs have been unable to build compelling business cases to deploy sufficient LV monitoring equipment to allow for adequate reporting of network-wide supply voltage magnitudes. This leaves data from smart metering devices as the most likely source of the data required. However, with the exception of Victoria, data collected by smart meter devices is owned by either the retailer or the metering provider and DNSPs are required to pay a fee to access the data. Once again, it has been difficult for DNSPs to develop compelling business cases to support payments for large volumes of voltage data collected by smart metering devices.

7 Distribution Network Service Provider Survey Results

As part of the investigations conducted during this project, a survey was distributed to the majority of Australian DNSPs to better understand their attitudes and actions in relation to management of supply voltage magnitude in low voltage networks. The survey questions were as follows:

1. What do you perceive to be the most significant impacts of poor voltage regulation on consumers?
2. What do you perceive to be the most significant impacts of poor voltage regulation on your business?
3. What activities has your organisation undertaken to better manage voltage regulation within low voltage networks?
4. In addition to the above, what further activities does your organisation intend to undertake in the short term?
5. Do you consider existing voltage management approaches are fit for purpose and adequate to deliver best outcomes for consumers?
6. What are your present after diversity maximum demand (ADMD) values and what situations are these applied in? Are there any plans to adjust these values? If so, what do you perceive to be the implications?
7. Are there any other comments that you would like to make with respect to management of voltage magnitudes in low voltage networks?

Responses were received from six DNSPs in 4 states with the outcomes summarised below.

7.1 Response to Question 1

The survey responses for Question 1 are summarised in Figure 7-1. Equipment maloperation and loss of life are identified as being impacts by the majority of respondents. Only a relatively small percentage of respondents identified additional energy use as an impact. In addition to the data shown in Figure 7-1, one DNSP also identified large swings in demand as being problematic.

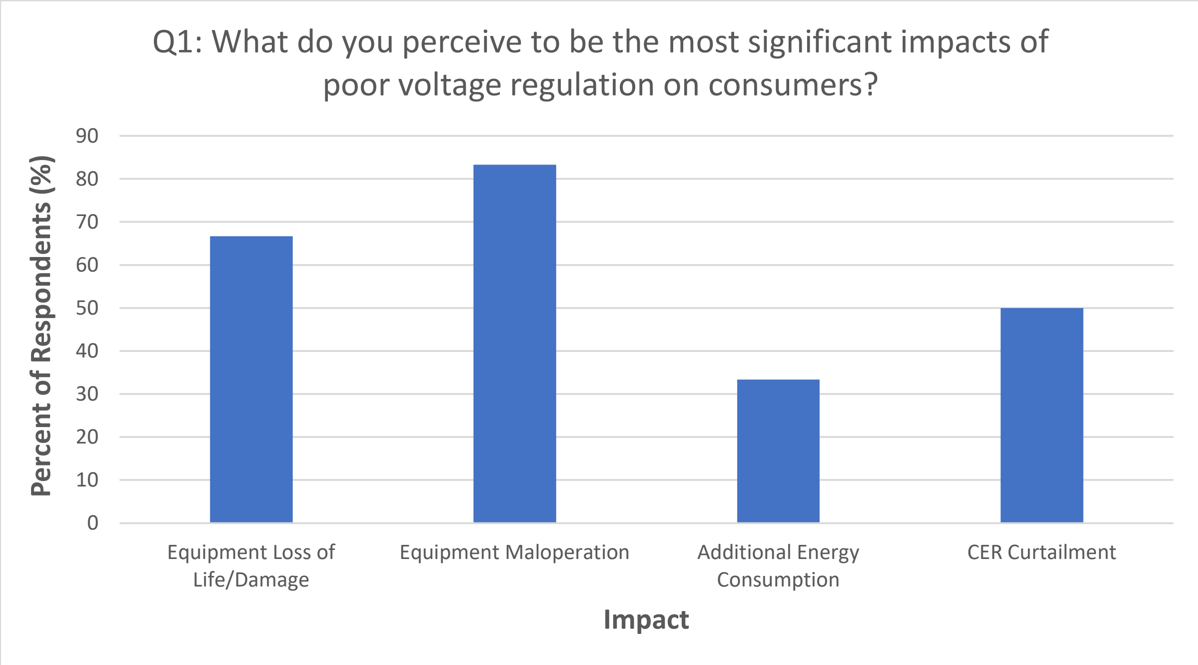

Figure 7-1: Survey Responses to Question 1

7.2 Response to Question 2

Responses to Question 2 are summarised in Figure 7-2. Consumer complaints, regardless of whether the DNSP was at fault, and the resources required to address them was identified as a significant issue by most respondents.

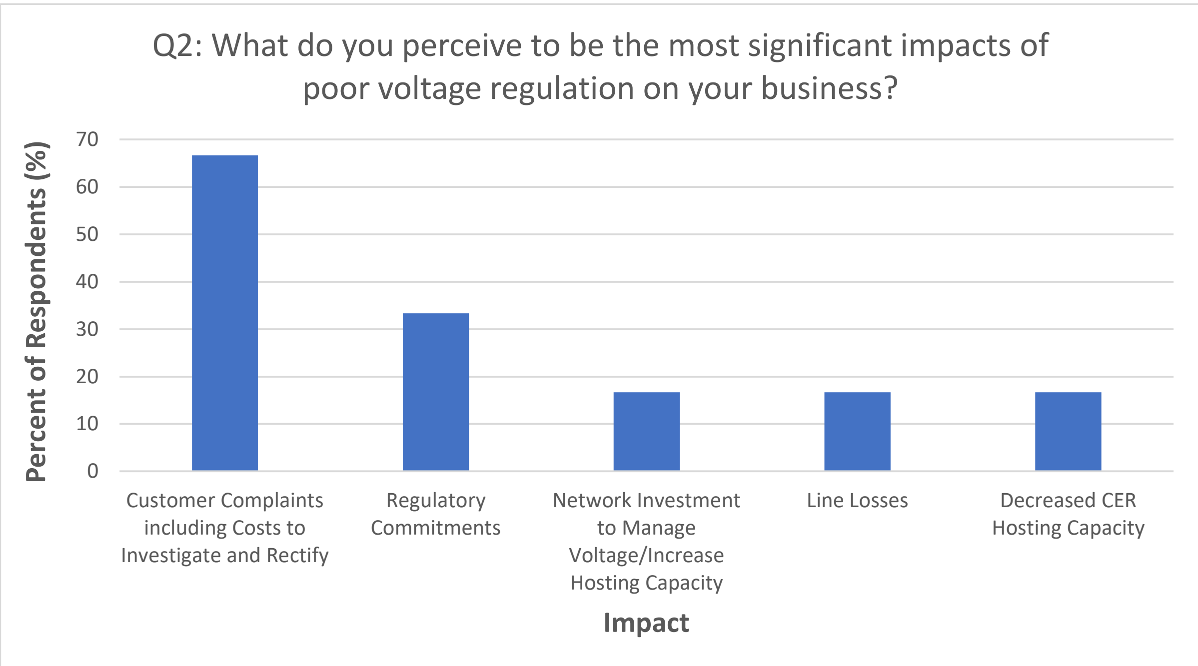

Figure 7-2: Survey Responses to Question 2

7.3 Response to Question 3

Responses to Question 3 are summarised in Figure 7-3.

Figure 7-3: Survey Responses to Question 3

All respondent DNSPs identified solar PV enablement activities in one form or another as activities that are being undertaken to better manage supply voltage magnitudes. Activities include:

- Adjustment of zone substation float voltages to provide widespread reductions in LV voltage magnitudes. One DNSP is also implementing time varying voltage setpoints based on predicted levels of solar generation while another is extending the tap ranges at zone substations.
- Use of controlled loads as a ‘solar soak’
- Use of energy storage (grid batteries)
- Use of LV STATCOMs and LV regulators

One DNSP identified augmentation of weak parts of the network.

Two DNSPs highlighted the importance of data to allow network performance visibility and indicated that they are purchasing power quality data to allow use of an analytics platform (which they have also purchased). In addition to purchasing data, one DNSP is installing permanent LV monitoring.

Other activities identified included:

- Implementation of co-generation mode on medium voltage regulators to allow for reverse power flow CER.
- Improving the process to address customer voltage complaints to achieve a faster resolution, including, following a confirmed high volts complaint:
    - Tapping distribution substation transformers on the spot.

- Changing out tap limited transformers in a 48-hour window.
    - One DNSP is transitioning from reactive customer enquiry driven works to proactive detection and remediation of voltage issues.
- Reducing the standard distribution substation transformer tap setting for all transformers leaving the transformer workshop.
- Use of on-load tap changing distribution transformers.
- Use of static models and smart meter data to specify recommended distribution substation transformer tap settings for the supply areas of zone substations and medium voltage regulators.

7.4 Response to Question 4

Responses to Question 4 are summarised in Figure 7-4. Here it can be seen that the majority of respondents nominated that they are working to implement dynamic operating envelopes (flexible exports) for CER, effectively solar PV generation. Half of the respondents are developing closed loop voltage control schemes which rely on smart revenue meter data (access to data being key to this initiative).

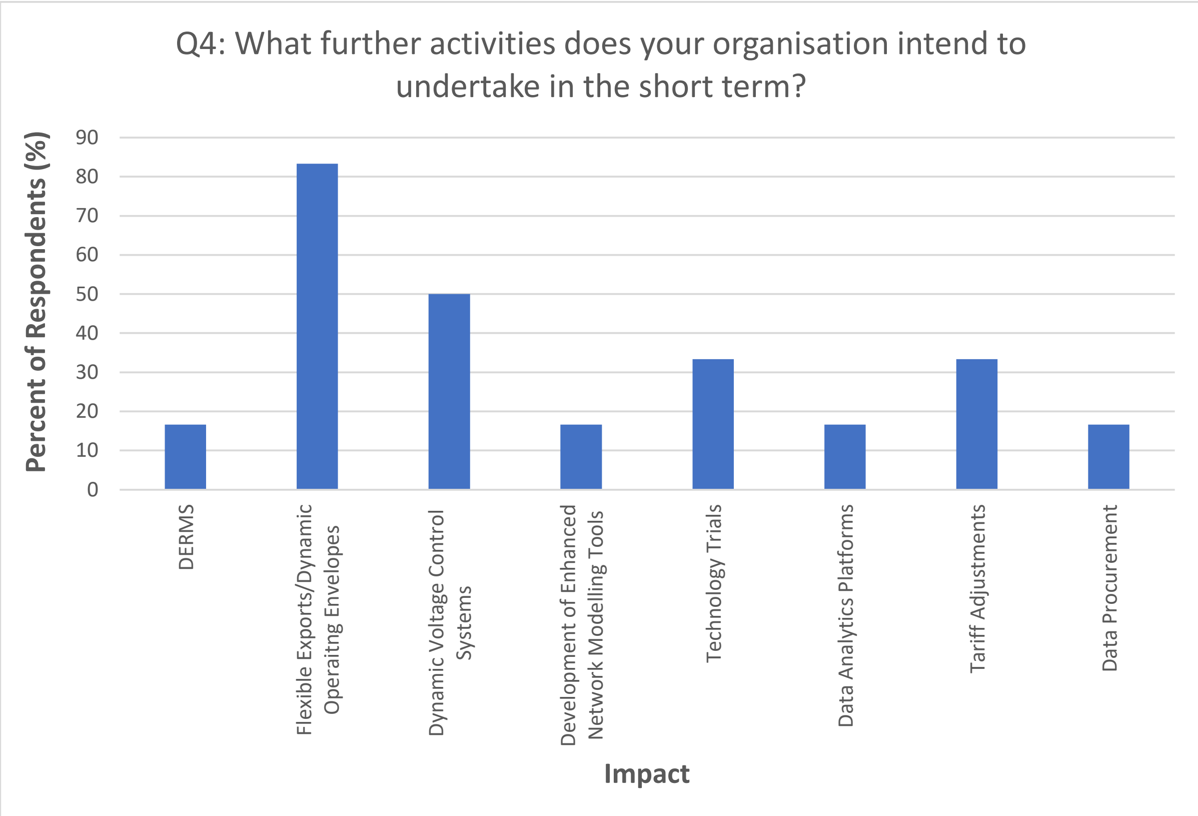

Figure 7-4: Survey Responses to Question 4

7.5 Response to Question 5

Most respondent DNSPs considered existing management approaches to be fit for purposes but many identified a need for enhancement/updating as CER penetration and electrification initiatives increase. Two DNSPs noted that new data sources (including real time monitoring) and technology shifts are creating much more effective means of enabling an effective voltage management/system of controls and provide a more targeted means of undertaking augmentation works where it is prudent and efficient. Another DNSP stated that existing approaches will not be enough in isolation to address the voltage problems arising from the future increases in CER and changing customer loads and behaviour more generally.

7.6 Response to Question 6

The ADMD values of one respondent indicated a variation of 2 kVA per dwelling between ADMD values where reticulated gas is available and where it is not. This suggests that networks designed to this standard may face significant capacity and voltage management challenges as dwellings transition to full electrification.

Five of six respondents identified that ADMD values are either being reviewed or will require ongoing review as electrification initiatives (including EVs) continue. One DNSPs stated:

"Electrification of both Gas sector and Transport sector will add to Household ADMD"

While another stated:

"We have recently revised our ADMDs due to the increase of household loads and restriction on gas connections for new premises in Victoria."

A third stated:

"The rapidly changing needs of customers, new technology and the significant amounts of generation coming from ever increasing amounts of customer energy resources means that there is a lot of potential variability in ADMD values moving forward. DNSP is already seeing asset ratings in new development areas being constrained by power generation rather than load demand. There is an opportunity for industry to consider future scenarios for ADMD values and their applicability."

7.7 Response to Question 7

Most respondents identified that management of supply voltage will be an ongoing challenge. One DNSP stated:

"Customers and Networks would benefit from additional work to better incorporate the cost of poor voltage regulation into modelling and business cases aimed at addressing poor voltage levels."

On DNSP identified emerging undervoltage issues as being of particular concern stating:

"As the Customer Electrification transition progresses, phasing out gas and increasing EV adoption will drive up demand on our networks. Undervoltage is likely to emerge as a challenging issue for our customers. Unlike overvoltage, which can be addressed more straightforwardly, undervoltage solutions often require capital-intensive investments due to our networks' wider voltage bandwidths."

One DNSP identified several emerging challenges related to phase balancing as the number of relatively large single-phase CER devices continues to increase. Retailer billing practice which is based on net power flow across phases rather than 'per phase' activity was identified as a concern. This is due to consumers exporting on one phase whilst importing on alternative phases, which will impact unbalance compliance on the network. Lack of a tariff structure to deter this unbalance leaves very little incentive for customers to balance their loads or install 3 phase devices.

8 Jurisdictional Regulator Survey Results

In addition to a survey of DNSPs, a survey was also distributed to state based jurisdictional regulators in order to gain insight into their perceptions of the importance of management of supply voltage magnitude and how they work with DNSPs. The survey questions were as follows:

1. What do you perceive to be the most significant impacts of poor voltage regulation on consumers? Alternate question – Has your agency been involved in any compliance monitoring or policy implementation activities in relation to poor voltage regulation in the state?
2. In addition to the above, does your organisation have plans to work with network providers to manage overvoltage and its impacts? Are there any policy developments that your organisation intends to undertake in the short term and long term?
3. Do you consider existing voltage management approaches implemented by distribution networks are fit for purpose and adequate to deliver best outcomes for consumers? Are you aware of any appliance failure data or consumer complaints specifically with regards to high voltage in the low voltage networks?
4. Are there any other comments that you would like to make with respect to management of voltage magnitudes in low voltage networks in your state?

Responses were received from the following regulators:

- Independent Pricing and Regulatory Tribunal (IPART) (NSW)
- Essential Services Commission of South Australia (ESCOSA) (SA)
- Department for Energy and Mining (SA)
- Department of Energy, Environment and Climate Action (DEECA) (VIC)
- Utilities Technical Regulation (UTR) (ACT)

8.1 Response to Question 1

There were varied responses to this question. Only one regulator provided feedback on impact of supply voltage magnitude on consumers stating that high voltages lead to increased energy consumption, reduced solar hosting capacity, and risk of appliance damage.

The compliance functions also varied significantly across respondents. A summary of responses is as follows:

- No direct compliance function for supply voltage magnitudes but requirements for reliability and technical standards for connection of CER.
- Dealing with voltage issues by exception.
- Only involved with compliance as a safety function.
- Oversight of the technical regulation aspects of network(s) including support of the Technical Regulator, to discharge its function of ensuring safe, reliable, and efficient delivery of regulated services (electricity transmission and distribution). This includes oversight of the monitoring and reporting activities in relation to a range of network related aspects, including network voltages.

8.2 Response to Question 2

Three of five respondents did not have any specific work planned in the area of voltage management.

One regulator is actively monitoring network voltages and intends to continue ongoing discussions with networks on any concerning trends, while recognising significant improvements where they occur.

The remaining regulator engages with the network provider on on-going basis for matters related to LV network voltages (under, over, dips, harmonics etc.). Following AEMC review report on metering service, published August 2023, and considering recommendations regarding 'unlocking benefits from smart meter and services', this regulator intends to strengthen the network monitoring and reporting requirements in the relevant Technical Code. However, this is not formalised, and no conversation has taken place with the network provider.

8.3 Response to Question 3

Once again, responses to this question were quite varied. Of the two regulators who directly answered the question whether existing voltage management approaches implemented by distribution networks are fit for purpose and adequate to deliver best outcomes for consumers, one answered yes (but are monitoring developments) while the other answered no (due to challenges related to CER integration). A third regulator indicated that their view is that the concept that net benefits exist through varying existing voltage management approaches is yet to be made.

In terms of complaints and appliance failure data, three of four respondents did not have data related to these aspects. The fourth respondent stated that reductions in voltage have "coincided with significant decreases in voltage complaints, and improvements in solar export capability for new solar customers."

8.4 Response to Question 4

Responses to Question 4 are as follows:

8.4.1 Regulator 1

The visibility of voltage levels in the low voltage network is low, but this is changing with information from both smart meters and those sites under a flexible connection arrangement with the DNSP.

Historically voltage issues have been managed by exception by the DNSP, where a customer would complain, the DNSP would install monitoring equipment then make any necessary changes to their infrastructure.

8.4.2 Regulator 2

Continued decreases in average voltages are expected to save customers in the state over $13 million per annum ongoing, which does not consider additional solar exports that have been enabled.

These savings are concentrated in three network areas that have seen average voltage fall between 4 – 5 V over a three year period. These are the only networks in the state that are operating DVMS. This is in trial phase in the other two networks, where average voltages have fallen less than 1 V over the same time period.

8.4.3 Regulator 3

The DNSP is aware of voltage issues in its network and is undertaking measures (either new and strengthening the existing ones) within the current regulatory environment and with approved funding from the economic regulator, however the aspect of the resolution timeline for voltage related complaints requires attention.

9 Review of DNSP Regulatory Submissions

A review has been undertaken of DNSP voltage control measures as determined from AER regulatory proposals. In particular, regulatory proposals to the AER were examined to determine if the impact of voltage levels on the energy use and lifespan of consumer equipment was a consideration.

The high-level outcome is that in no jurisdiction across Australia that is under AER oversight was the relationship between supply voltage magnitude and either energy consumption or appliance lifespan considered to be an issue. The submissions indicate that the main concern over the next 5 years is the integration of CER into LV networks, this being achieved through a range of activities including network augmentation, dynamic voltage management (in combination with smart meter data collection and analysis), and tariff structure. The different DNSPs apply these and other methods in varying degrees.

Extracts from the proposals to the AER for the stated regulatory period for the various jurisdictions are given below to indicate the methodology, costs and tariffs used.

9.1 ACT – Evoenergy (2024-29)

The Evoenergy submission states that the "*sheer scale of transition will require significant network reinforcement, effectively the reshaping of our existing network. We expect that this will require in the order of $2.5–$3.0 billion of investment.*" For the 2024–29 regulatory period, modelling indicates that to achieve a steady pathway to net zero by 2045, an investment of the order of $0.75 billion ($2023/24) is required. Reliability and quality of supply spend is proposed to be $12.3 million over the period.

According to the submission, "*Evoenergy's electricity network needs to continue to evolve from a one-way network to wo-way flows across the network. This will require surmounting the technical engineering challenges from an increasing penetration of geographically distributed asynchronous generation (such as energy from solar and batteries), such as voltage and frequency stability issues. To ensure power quality standards are met, the Evoenergy electricity network will need to play a more active, innovative, and smart role than in the past (for instance, through the installation of devices such as online tap changers to manage voltage issues).*"

Evoenergy is undertaking a suite of measures to manage the expected increase in peak demand including:

- The EVGrid trial, where Evoenergy is collaborating with electric vehicle owners to test dynamically managing charging based on real-time assessment of available network capacity.
- Designing tariffs that are appropriate for changing the use of the network while sending price signals that promote efficient use of the network for EV charging to reduce the impact on the network.
- The Ginninderry Residential Battery Trial, where Evoenergy is enabling battery owners to collaborate with Evoenergy to alleviate network congestion.
- Battery tariff trials, such as residential battery tariffs and large-scale battery tariffs, to explore the potential of tariffs with sharper pricing signals.

- The Realising Electric Vehicles-to-grid Services project which explores how these services can be part of the future energy system.
- Establishing a test facility at the Australian National University to allow for safe testing of new DER-based technologies.
- Enhancing visualisation of network capacity to allow better informed strategic customer decision making on EV charging infrastructure.
- Distribution Network Monitoring - with the increasing penetration of micro-generators such as PVs, the introduction of fixed batteries and EV batteries on the network, there is an increasing need to extend network monitoring to lower levels of the network to maintain existing levels of reliability.

Tariffs

Evoenergy is proposing a 'solar soak' tariff during the middle of the day, designed to encourage the use of electricity to soak up solar that would otherwise be exported. A 'solar reward' to conversely pay for electricity exported during peak demand when it's most needed is also proposed.

Evoenergy's submission states "*In recent years, imbalance between the supply and demand of electricity has been widening. This typically arises in residential areas in the middle of the day when demand for electricity is relatively low and exports from rooftop solar PV is high. As the imbalance continues to widen, additional investment will be required to manage voltage fluctuations on the network. Evoenergy proposes to introduce export pricing in a measured and gradual manner. This is reflected in Evoenergy's proposed export tariff structures, tariff levels and assignment policy.*" Evoenergy is also proposing the following:

- For residential demand tariffs:
    - Introduce a relatively low solar soak energy charge between 11am and 3pm AEST.
    - Introduce an off-peak demand charge between 8pm and 9am AEST
- A residential export tariff (secondary tariff):
    - Export reward (in cents per kWh) for all exports during the evening peak period (5pm-8pm AEST).
    - Export charge (in cents per kWh) on exports during the solar soak period (11am-3pm AEST) above the basic export level (5 kW).

9.2 New South Wales

9.2.1 Ausgrid

Ausgrid state that there is a relationship between growth capex and CER integration capex. The submission states that charging EVs can use a lot of electricity over a very short period and that they are already seeing chargers on the market with substantial capacities that could lead to significant new demand peaks on the network, including:

- Commercial chargers with up to 350 kW capacity; and
- Home smart chargers with a typical capacity of 7 kW.

Ausgrid contend that the time of day when customers charge their vehicles will be crucial, in addition to the location where this occurs – for example, at home, at a public charging station, or in an area of the network with a lot of solar generation. Ausgrid recognises that tariffs need to send efficient price signals about the different costs of charging EVs at different times so that EVs do not lead to a significant uplift in growth CapEx. The Ausgrid residential demand and time of use (TOU) tariffs signal the higher costs of charging in the evening peak period and encourage charging overnight when network demand is low. It is proposed changes to the charging windows for these tariffs will strengthen these signals.

The Ausgrid network, ICT and innovation capex programs all include elements of CER integration. Ausgrid also plan to employ OpEx based initiatives, innovative tariffs and dynamic connection agreements to efficiently integrate CER. Figure 9-1 shows the technical challenges arising due to CER-led network transformation as identified by the Ausgrid submission.

	Problem	Impact
Hosting capacity	High voltage levels at times of peak exports from rooftop solar	Solar customers are unable to export energy back to the grid, preventing them from achieving the full benefit of their investment
Network overload	Concentrated areas of CER exports or loads, such as electricity vehicles and batteries, causing overload of the network	Loss of supply due to failure of the network

Figure 9-1: Technical Challenges Arising due to CER-led Transformation of the Ausgrid Network [13]

Ausgrid proposes to manage CER integration through strategies other than investment, including innovative tariffs and dynamic operating envelopes. Figure 9-2 shows Ausgrid's hierarchy of potential responses to CER challenges.

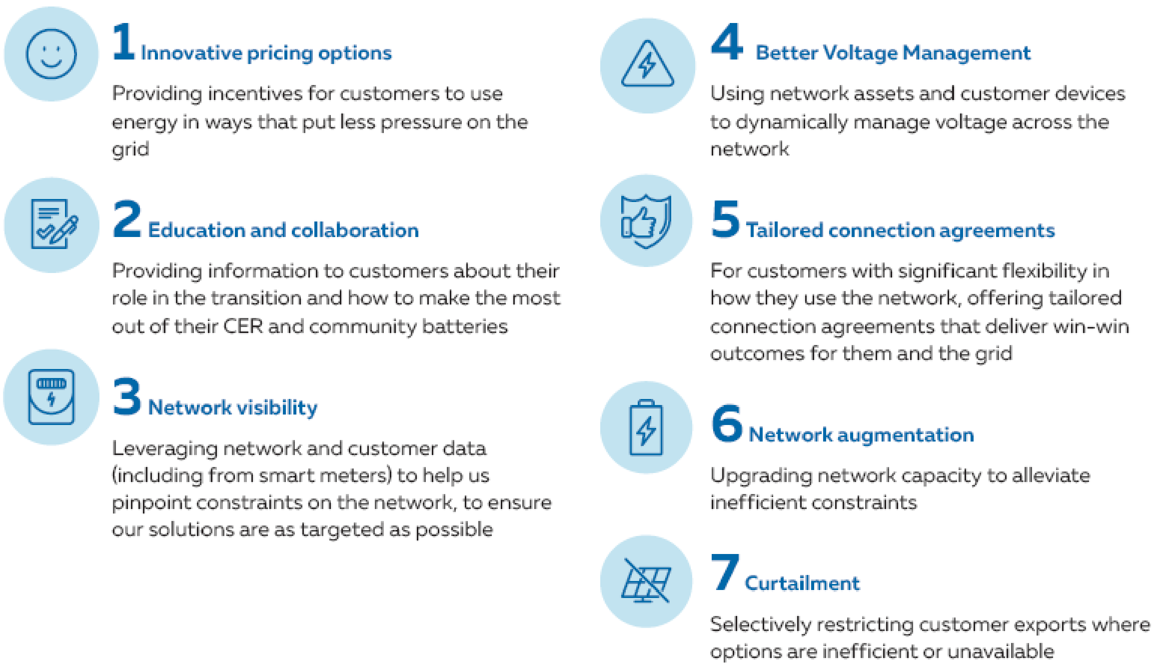

Figure 9-2: Ausgrid Hierarchy of Potential Responses to CER Challenges [13]

Figure 9-3 shows Ausgrid's CER integration investment options.

Option	Description	Total Cost 2024-29	NPV FY24
Option 1 Base Case	• Address CER with our current capabilities and static network settings • Most investment is through traditional network augmentation	$50.3	(2.9)
Option 2 Preparatory Investment	• Improved network visibility to manage complex power flows through better understanding of the network and optimising network investment • Digital tools that improve the experience of connecting CER and network information available • Customer education resources to improve customer literacy about technology, services and benefits • Primarily traditional network augmentation where economically justified	125.0	48.8
Option 3 Proactive investment (proposed)	• Providing incentives to customers through innovative connection and pricing options to use their energy in ways that puts less pressure on the grid • Improved network visibility to manage complex power flows through better understanding of the network and optimising network investment • Customer education resources to improve customer literacy about technology, services and benefits • Deploying a mix of traditional augmentation and flexible network solutions. This includes distribution substation tap changes, phase balancing, distributor augmentation, STATCOMs and community batteries	126.1	169.4

Figure 9-3: CER Integration Investment Options ($m real FY 24) [13]

As metering technology has improved, Ausgrid has been able to implement several pricing reforms to make residential and small business tariffs more cost-reflective and to give customers more power to influence their bills, including introducing:

- TOU pricing for small customers with interval ready meters in 2003. These prices have a range of ‘charging windows’, so customers pay a higher rate for energy used during the periods of peak demand on their network.
- Demand pricing for new residential and small business customers with smart meters in 2019. These tariffs apply to a customer’s metered peak demand that occurs over a month and within the peak period window.

Ausgrid are proposing six main changes to tariffs:

1. Introducing export pricing for residential and small business customers after a 1-year transition period to reflect the increasing costs that receiving CER customers’ exports imposes on the network and provide an incentive for CER customers to self-consume or time their exports to minimise these costs and maximise the benefits they receive.
2. Introducing tariffs for embedded network operators that will better reflect the costs (over a transition period) that these business customers impose on our network, so they make a fairer contribution to funding these costs.
3. Streamlining existing tariff offerings and tariff assignment policies for customers to make it easier for retailers to respond to or pass through price signals to customers.
4. Simplifying and updating the charging windows for demand, capacity and TOU tariffs to make it easier for retailers to pass through price signals to customers, and ensure peak charges apply when network demand is highest.

5. Introducing pricing for utility scale storage facilities to enable large batteries connect to the network and create a level playing field for projects located in the distribution network.
6. Updating controlled load tariffs for residential and small business customers to reflect changes in the times of day when demand on the network is lowest, and allow our 470,000 controlled load customers to operate their hot water systems during the day when solar energy production is highest.

9.2.2 Endeavour Energy

The Endeavour Energy submission [12] states that the primary driver of AugEx and connections CapEx over the 2024-29 period is extending their network into greenfield development areas where there is no, or very little electricity services available. Whilst CER CapEx is to support the ability of customers to connect and export CER across our low voltage network.

Endeavour Energy intend to adapt their suite of cost-reflective tariffs and introduce export rewards and charges along with specific tariffs for grid-scale batteries. Endeavour Energy have also developed a CER Investment Strategy that sets out a process for identifying and alleviating export hosting constraints.

In terms of cost-reflective tariffs, Endeavour Energy is seeking to improve the cost-reflectivity of tariffs by adapting them for export generation and new battery technology. The proposed tariff structure will provide customers greater incentive and control to manage their energy usage during peak periods (including export peak periods) in order to reduce future investment needs and prices. Figure 9-4 shows the proposed CER related capex for the FY25 -29 period.

$m; Real FY24	2024-25	2025-26	2026-27	2027-28	2028-29	Total
Distribution Substation LV Monitoring	2.3	2.3	2.3	2.3	2.3	**11.7**
LV Planning	6.7	6.7	6.7	6.7	6.7	**33.3**
Total	**9.0**	**9.0**	**9.0**	**9.0**	**9.0**	**45.0**

Figure 9-4: Endeavour Energy Proposed CER Capex for the FY25-29 Period [12]

The Endeavour Energy proposed program of work focuses on four key areas investment:

- Enabling systems
- Tariff reform and demand flexibility
- Network capability and operational optimisation
- DSO operations

In conjunction with the Australian Power Quality Research Centre at the University of Wollongong, Endeavour Energy has developed a deterministic LV simulation tool that:

- Builds customer load profiles from an available sample of smart meters, solar profiles based on historical irradiance data, and assumed battery and EV charging profiles from AEMO and CSIRO.
- Builds LV models for each of Endeavour Energy’s residential LV circuits based on the ADMS LV network electrical model data.

- Adjusts customer profiles based on our CER forecast and forecast scenario.
- Runs average daily as well as full year time series power flows simulations between now and 2040, calculating inverter curtailment energy as well as baseline and forecast power flows and voltage levels.
- Simulates the benefits of operational interventions such as distribution transformer optimisation and Dynamic Voltage Management as well as identify which LV circuits remain constrained after applying operational optimisation and where a network investment intervention is economically justified.

Enabling Systems

Endeavour Energy state that LV visibility and analytics (LVVA) is critical to efficiently supporting two-way energy flows from CER and for networks to deliver their DSO functions in line with regulatory reform. It enables improved hosting capacity through operational actions and dynamic LV voltage management, improving the utilisation of existing network assets. LVVA underpins all the intervention actions included in the Endeavour Energy proposed CER Integration Plan. Endeavour Energy have assessed multiple visibility sources for 2024-29 and consider smart meter power quality data access and distribution transformer monitoring to be the most mature, proven, and consistent sources. Endeavour Energy have also assessed the minimum viable level of visibility required to support several CER intervention actions. Across all these CER targeted use cases for LV Visibility, a common minimum access requirement is 20-25% broad based visibility with increased visibility beyond this targeted to specific areas of the network with high CER utilisation. Without this base visibility, many of these use cases could not be achieved.

Tariff Reform and Demand Flexibility

As an initial step to increase CER hosting capacity on the network Endeavour Energy plan to introduce new tariffs which will help manage the constraints that are forecast. A feature of this is the Solar Soak tariff trial which provides a two-way tariff and solar soak period to incentivise export shift to peak windows which are outside of the middle of the day. Endeavour Energy have modelled the impact of this tariff on customer behaviour out to 2040 by adjusting baseline customer load profiles. Similarly, utilisation of flexible demand through the Off Peak Plus pilot project during the current period has been trialled. This project successfully demonstrates smart meters can be used to deliver flexible and reliable hot water solar soaking through dynamic control.

Network Capability and Operation Optimisation

Endeavour Energy is seeking to optimise the operation of network by:

- Using their LV analytics platform to identify opportunities for phase balancing, through operational actions like tap optimisation.
- Implementing more advanced approaches to voltage management, such as implementing dynamic voltage management systems, to adjust target voltage settings at the zone substation level in real time.

Following these activities, it is proposed that network capability can be improved through investments including distribution transformer tank replacement, LV STATCOMs, LV network amplification and splitting and network support (e.g. batteries).

Network Visibility

Endeavour Energy state that LV network visibility is a foundational and enabling step in their CER Integration Strategy. It enables improved hosting capacity through operational actions and dynamic LV voltage management, improving the utilisation of existing network assets. LVVA underpins all the intervention actions included in our proposed CER Integration Plan. Endeavour Energy have determined broad based visibility of 20 - 25% is required and increased levels in targeted areas of high CER utilisation.

Solar Soak / Off-Peak Conversion

The Endeavour energy submission states that smart meter control allows for more flexible control of the hot water heating times at the individual customer level by sending control signals direct to each meter through the meter provider's remote API control interface. Both the network and retailer have access to control each meter, allowing both network management and retailer delivered market services (allowing for new customer offers).

It is stated that the Off Peak Plus program provides tremendous benefits to customers by soaking up excess solar energy during the day, providing a discount tariff. In addition to the benefits that solar soaking can provide this investment is also an alternate to:

- Replacing like for like end-of-life off-peak ripple control systems in existing substations.
- Installing new ripple control systems in a new substation that partially supplies an existing brownfield area where not all customers have transitioned to smart meters yet.

9.2.3 Essential Energy

The Essential Energy submission [14] states that the most immediate challenge for their network is accommodating and managing increasing levels of exports and demand from the increasing uptake of CER. According to the submission, without pre-emptive investment and management, increasing CER connections will:

- Create greater levels of volatility on the network – CER are inherently unpredictable, causing rapid load fluctuations on the network. For example, when a cloud goes over a neighbourhood the level of solar output suddenly drops in that area. Or, if everyone plugs in their EV after work, this will cause a huge increase in peak demand.
- Result in more power quality issues – Essential Energy forecast that over 50% of their customer base will begin to experience power quality issues by 2037 without network improvements, or changes to pricing.

Essential Energy have developed a plan for a staged rollout of investments in future network capabilities. The proposed investments will allow better visibility and control of the network to support greater volumes of CER exports using our existing assets. Essential Energy plan to use advanced monitoring equipment, innovative pricing and dynamic controls to flexibly manage the strains on the network. Figure 9-5 shows the proposed investment for CER enablement in the Essential Energy submission.

	Investment 2024-29	Investments supported by our customers 2024-29	In the future 2029-34
Network Visibility assets	$21M	> Assets in place to allow for basic real-time monitoring in local network areas	> Dependent on smart meter rollout, further investment may not be required
Data management system	$66M	> IT systems in place to integrate network visibility assets and other data for real-time monitoring for basic DOEs	> Expanded capability to monitor and control the network for advanced DOEs
Smart meter data	$16M	> Subscribe to data points prioritising areas with existing and emerging power quality issues	> Expanded data points to capture the broader network
Dynamic assets and traditional augmentation	$67M	> Invest in localised areas with existing and emerging power quality issues	> Dependent on impact of DOEs, tariffs and CER uptake
Batteries	$1M	> Engagement with third parties for the use of batteries to assist with local voltage management	> Dependent on battery costs, impact of DOEs, tariffs and CER uptake

Figure 9-5: Essential Energy CER Enablement Investment [14]

Essential Energy forecast system capex to facilitate CER during the 2024–29 regulatory period to be $88 Million. They have identified a range of capital investments in this area that make sense for their business, including:

- Upgrading targeted powerlines to increase thermal capacity.
- Replacing selected distribution transformers and adding on-load tap changers.
- Investing in real time network monitoring to improve low voltage network visibility, this includes software and systems to enable CER adoption.
- Enabling flexible export limits.
- Installing battery energy storage systems on the low-voltage network.

Essential Energy have also identified that pricing could also help to solve challenges that the network faces by:

- Encouraging consumers to use less energy during evening peak periods.
- Encouraging consumers to use more energy in the peak midday export period.
- Encouraging consumers to make better use of self-generated energy

The proposed tariffs include pricing based on the electricity consumed, and the introduction of export prices for electricity export.

9.3 Victoria

9.3.1 AusNet Services (2021-26)

The AER's Draft Decision, allows for investment of $58.9 million on DER enablement activities. It is stated that this DER investment will allow AusNet Services to meet most of their customer expectations and that they will be able to maximise the value of their DER investment during the 2022-26 regulatory period. Specifically, the DER program will only allow network upgrades to facilitate DER exports where it is economically justified. This means an estimated 7,000 DER customers will remain without any voltage improvement (as it is not economic to upgrade the network to address the constraints they face). AusNet Services consider, and it has been agreed by their Customer Forum, that such an approach appropriately balances the costs and service outcomes for our customers.

Since 2014 AusNet Services have lowered float voltages which has resulted in a 15% improvement in voltage compliance. However, in many places, adjusting LDC has run its course and AusNet Services are now observing an increase in non-conformance with the lower end of the voltage range during peak demands (for heating hot water and summer peaks) as the voltage bandwidth increases. To lower float voltages further some design issues with existing Voltage Regulating Relays (VRRs) must be addressed.

Issues Limiting the Hosting Capacity of the Ausnet Services Network

With increasing distributed and passive solar PV being connected, and with more minimum or reverse power flows occurring, it is stated that existing Voltage Regulating Relays are limiting the hosting capacity of the AusNet Services network in two ways:

- Compensated settings limit the hosting capacity for export.
- Line drop compensation requires existing relays to measure the magnitude of the current and increase the voltage in proportion, overcoming the voltage drop and ensuring a satisfactory voltage is achieved at the end of line.

As existing voltage regulating relays cannot identify the direction of current flow, where reverse flows are present, they can boost voltage levels, adding to the voltage rise, exacerbating non-compliance and limiting hosting capacity. By 2026 AusNet Services expect that greater than 89% of their zone substations will experience reverse power flow and this type of control will not be suitable for a high solar PV export. Flat or uncompensated settings limit the hosting capacity for load. This occurs when voltage levels are optimised lower or mid-range of the allowable steady state range. This lower voltage increases headroom for voltage rise but decreases the amount of load that can be carried and results in an increase in low voltage non-compliance during peak demand days. Using flat settings, a 15% improvement in compliance with the upper limit of the Victorian EDC has been achieved. However, an increase in low voltage non-compliance is now being observed.

As such, AusNet services state that there is a need to increase the functionality of the VRR (by upgrading equipment) to enable bi-directional voltage control and maintain capacity for demand and increase capacity for generation exports.

9.3.2 CitiPower (2021-26)

CitiPower forecasts that investment required to maintain supply quality in their LV network over the 2021–2026 regulatory period includes the following:

- Re-balancing phases to prevent single phase overloads.
- Upgrades to conductors to prevent voltage drop or allow additional load to be connected.
- Replacement of transformers that are overloaded (proactively rather than replacing under faults).
- Changing conductors or transformers to address harmonics, flicker or other power quality problems.

Figure 9-6 shows the supply quality investment based on observed supply quality interventions. As shown investment trends upwards over the 2021–2026 regulatory period in line with load growth expectations for existing and new customers.

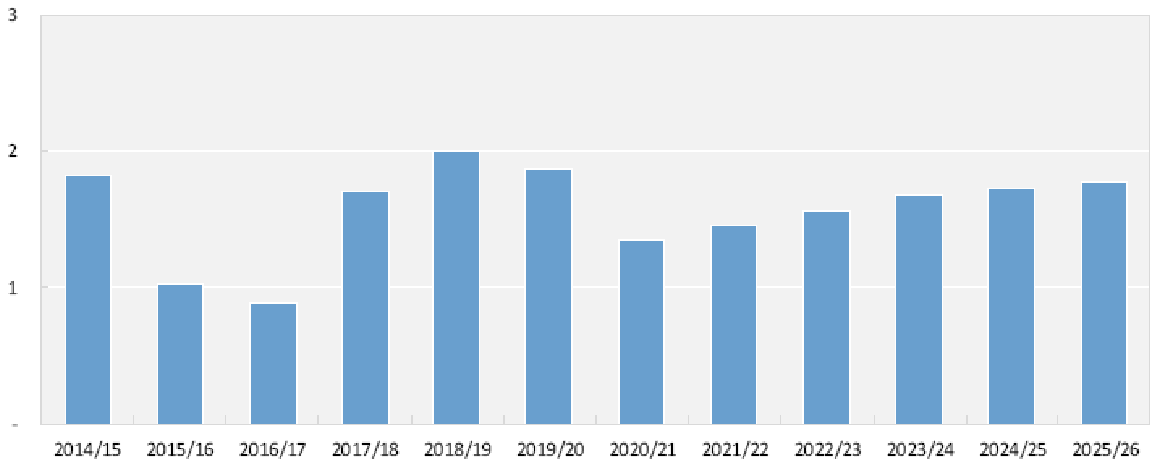

Figure 9-6 :CitiPower Forecast Supply Quality Investment [15]

The CitiPower submission states that availability and use of smart meters in Victoria and other states differ markedly. While all customers with smart meters benefit from the savings of moving from manually to remotely read meters, Victorian customers also benefit from the rich source of power quality data for network management and optimisation. Only Victorian smart meters are required to be installed with functionality that means this data is collected.

Victorian smart meter functionality is essential to meeting the CitiPower technology vision for the network including providing full visibility of the LV network as outlined in the CitiPower digital networks proposal and managing the increasing penetration of rooftop solar (and other technologies) that will lead to more exports on the network and the need to manage two-way flow and voltage variations.

In 2018, power quality data accounted for 88% of all data collected and transmitted through the smart meter communications network. CitiPower expect this share to remain relatively constant by 2025/26.

CitiPower have identified that the higher network voltages caused by solar means that if they do nothing, customer solar will be automatically constrained by their inverters and they will lose the benefit of solar. CitiPower have used advanced analytics and smart meter data to determine the most efficient way to remove solar constraints so that most customers can export with a 5 kVA system. Over the 2021–2026 regulatory period this project will allow CitiPower to unlock over 95% of the solar that would otherwise be constrained while maintaining affordability.

CitiPower are also preparing their network to enable more solar. It is stated that an important component to ensure this occurs at the least-cost for customers is developing a dynamic voltage management system—an IT system to remotely and dynamically manage network voltages at the zone substation level of our network.

CitiPower are also proposing the tariff structure shown in Figure 9-7.

Proposed tariffs	Proposed assignment	Tariff options (upon request from retailer)
New ToU	New connections Supply upgrades to three-phase Households installing solar or battery Existing flexible tariff customers	Single-rate or demand
Single-rate	All existing customers remain	New ToU or demand
Legacy ToU	All existing customers remain	Single-rate, new ToU or demand
Demand	All existing customers remain	Single-rate or new ToU
Dedicated circuit	All existing customers remain	Single-rate, new ToU or demand

Figure 9-7: CitiPower Proposed Tariff Structures [16]

9.3.3 Powercor (2021-26)

The Powercor submission [17] is very similar to that for CitiPower. Powercor forecast that $11 million is required to maintain supply quality in the 2021-2026 period.

9.3.4 United Energy (2021-26)

United Energy are seeking to get the most out of their existing network through a digital network program by:

- Significantly expanding demand management capabilities by developing a platform to facilitate market led demand management across low voltage assets. This will reduce augmentation costs for all customers, particularly when electric vehicles take off in Victoria, and is critical for integrating intermittent renewables into the market.
- Developing dynamic operating envelopes to better manager DER. This includes ensuring DER operates within the bounds of the network's capacity to minimise disruption and ensure customers get fair access. It also supports new business models such as virtual power plants by providing visibility on the amount of DER available to them at any given point in time.

United Energy are seeking to prepare the network for more DER where this is efficient through a solar enablement program—by leaning heavily on technology such as their dynamic voltage management system. This is complemented by traditional approaches such tapping transformers and network augmentations, where the benefits to customers exceed the costs.

United Energy have developed time of use tariffs to encourage customers to use more electricity in off peak times and times of higher solar production. A summary of these tariffs is shown in Figure 9-8.

United Energy have also partnered with the Australian Renewable Energy Agency (ARENA) in a pioneering trial of pole mounted batteries which will charge at times of the day when there is low demand or rooftop solar systems are exporting to both alleviate solar and peak demand constraints. United Energy have also partnered with ARENA and Origin Energy to undertake a large-scale trial to demonstrate the use of smart chargers to manage residential and fleet electric vehicle charging.

Through connection guidelines and connection model standing offers, United Energy are mandating smart inverter settings to be applied to all new solar installations. This means solar connections will have less impact on constraining the network.

Proposed tariffs	Proposed assignment	Tariff options
Default ToU	New connections Supply upgrades to three-phase Households installing or upgrading PV solar or battery Existing legacy and flexible ToU customers Electric vehicles and/or electric vehicle chargers[2]	Single-rate[3] or demand
Single-rate	Existing winter energy tariff customers All existing customers remain	Default ToU or demand
Demand	All existing customers remain	Single-rate or default ToU
Dedicated circuit	All existing customers remain	Any new eligible load

Figure 9-8: Summary of United Energy Residential Tariffs [18]

9.4 Queensland (2025-30)

9.4.1 Energex

The Energex submission [19] states that "*the transition to a net zero emissions future and the increasing solar generation from rooftops and large solar farms during daylight hours has meant that Energex must develop strategies to manage the challenge of low energy demand during the day, which can cause power quality issues that can be harmful to customer appliances as well as the network.*" [19]

Due to the high volume of solar generation installed, Energex are already observing new daytime lows in minimum demand creating reverse power flows in localised parts of the network and stability concerns that could intensify the risk of blackouts in the coming years. Consequently, Energex are proposing to deliver integrated solutions that will help make the best use of generation and deliver benefits and opportunities for both customers and the network.

Solutions proposed include changing network tariffs to encourage greater energy use during periods of high solar export, expanding demand management programs, and dynamic operation of the network to manage DER more efficiently and limit the need for network investment.

The key areas of focus to facilitate customer opportunities in the transition to renewable energies for the 2025-30 regulatory control period are:

- Implementation of new network tariff structures - While network tariffs play an important role in improving price equity across all customer groups, they also send price signals intended to improve network utilisation and avoid or defer future investment in congested parts of the network. For the next regulatory control period Energex see further opportunities to explore solutions that increase the efficiency of tariffs to encourage customers to use the network in ways that limit the need for future network augmentation and reduce the prices they pay for electricity.

- Offering dynamic connection agreements – it is stated that dynamic connection agreements will allow households and businesses to access new and emerging energy technologies as they become available. Dynamic connections seek to give customers choice about connecting the energy resources they want, while minimising impacts to the grid by communicating varying import and export limits to the customer's energy resources. Dynamic connections will allow more households to install rooftop solar and batteries and take advantage of the associated cost benefits.

- Expanding demand management programs - Energex plan to continue to build on long-standing and well-established demand management programs to lower network AugEx, reduce consumer bills and provide a greater balance between demand and renewable generation. An expanded demand management program, which will continue to include existing air-conditioning and hot water load control programs, is proposed to work alongside dynamic connections, cost-reflective tariffs and battery energy storage to ensure that Energex can effectively integrate renewables, while continuing to ensure affordable, safe and reliable network operation

The Energex DER Integration Strategy outlines the benefits to customers of having more network visibility to unlock export. There are three elements to this expenditure:

- Distribution transformer monitors – establishing grid visibility on transformers exhibiting high export penetration. These monitors have benefits beyond DER integration, including reduced response time to outages, resulting in improved reliability and planning functionality uplift from the use of the data.

- Low voltage monitors - installing a small quantity of low voltage monitors to measure power quality at the customer's premises. This investment is part of the Energex Smart Meter Data Acquisition Business Case, and provides safety, reliability and financial benefits in addition to the DER integration case, and

- Telemetry hub expansion – this expansion will improve capability to have data delivered and analysed as part of our state estimation and dynamic operating envelopes framework.

Approximately $914 million (27%) of the Energex forecast five-year capex program is slated to replace or refurbish existing network assets that are ageing and/or in poor condition, $610 million (18%) is to reinforce areas of the network experiencing growth, reliability, or power quality issues, $56 million (2%) is to integrate DER into the network.

Energex state that "*existing visibility of power flows and other information on our low voltage networks is very limited.*" The rollout of smart meters across the Energex network will provide the opportunity to actively monitor the low voltage network. Energex propose the following step change in smart meter use:

- Acquiring advanced (near real-time) power quality data for 25% of the available smart meters, which is the critical mass of data required for a highly accurate real-time assessment of the low voltage network to enable the integration of DER and export at the most efficient level.
- Acquiring basic power quality data for the remaining 75% of smart meters of overhead service lines. This will enable detection of emerging defects and failures on service lines to prevent safety and reliability issues for customers. This data is assumed to be free of charge in accordance with the AEMC's recommendation.

Tariffs (Smart Meters)

Figure 9-9 shows the proposed Energex tariff structure. Energex state that two-way tariffs provide rewards for customers who export energy at times most likely to trigger investment due to high import demand. Charges above a basic export level are aimed at ensuring that future network investment required to manage exports in the middle of the day is paid by those causing that investment. Figure 9-10 shows the proposed residential two-way tariff framework.

Network Tariff	Parameter	Unit	Description
SAC Small Primary Tariffs			
Residential TOU Demand & Energy (NTC3900) Default for all Customers. Previously known as Residential Transitional Demand.	Fixed	$/day	Daily supply charge
	Volume Shoulder	$/kWh	For energy consumption between the hours of midnight to 11am and 9pm to midnight daily
	Volume Off-Peak	$/kWh	For energy consumption between the hours of 11am to 4pm daily
	Volume Peak	$/kWh	For energy consumption between the hours of 4pm to 9pm daily
	Peak Demand	$/kW/month	Charge applied to the single highest 30-minute kW demand during the month between the hours of 4pm to 9pm daily
Residential TOU Energy (NTC6900) Previously known as Residential Time of Use Energy.	Fixed	$/day	Daily supply charge
	Volume Shoulder	$/kWh	For energy consumption between the hours of midnight to 11am and 9pm to midnight daily
	Volume Off-Peak	$/kWh	For energy consumption between the hours of 11am to 4pm daily
	Volume Peak	$/kWh	For energy consumption between the hours of 4pm to 9pm daily

Figure 9-9: Proposed Energex Tariffs adapted from [20]

Network Tariff	Parameter	Unit	Description
Residential Two-Way (NTCTBA)	Export Charge	$/kW	Charge applied to single highest 30-minute kW during the month between the hours of 11am to 4pm daily above 1.5kW
	Export Reward	$/kWh	For energy exports between the hours of 4pm to 9pm daily

Figure 9-10: Proposed Residential Two-way Tariff Framework adapted from [20]

9.4.2 Ergon Energy

The Ergon Energy submission [21] states that "*The transition to a net zero emissions future and increasing solar generation during daylight hours has meant that Ergon Energy Network must develop strategies to manage the challenge of low energy demand during the day, which can cause power quality issues that can be harmful to customer appliances and the network.*"

Ergon Energy are proposing to deliver integrated solutions that will help make the best use of generation and deliver benefits and opportunities for both customers and their network. Proposed solutions include changing network tariffs to encourage greater energy use during periods of high solar export, expanding demand management program, and dynamic operation of the network to manage distributed energy resources more efficiently and limit the need for network investment.

Ergon Energy have identified challenges associated with minimum demand on the network during periods of high solar PV generation. Ergon Energy state that these challenges require investment in infrastructure to manage the energy being exported to the grid and ensure the reliability of supply. It is also stated that efficient pricing will encourage more use of energy in the middle of the day to allow more solar to be connected without impacting future costs. Figure 9-11 shows the forecast capex for Ergon Energy for the period 2025-2030. As part of forecast operating expenditure requirements for the five-year period, Ergon Energy have included costs of sourcing power quality data from smart meters.

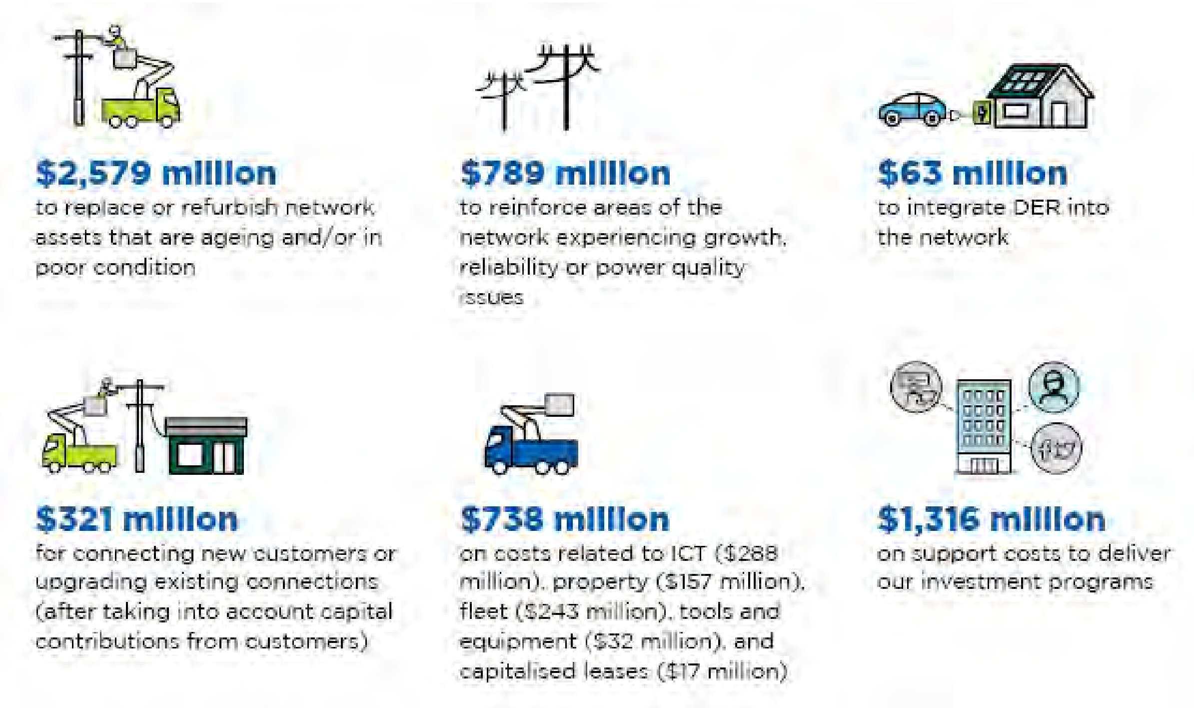

Figure 9-11: Ergon Energy Forecast Capex 2025-2030 [21]

Tariffs

As for Energex.

9.5 South Australia – SA Power Networks (2025-30)

The SA Power Network submission [22] states that "*As rooftop solar continues to grow in the 2025-30 period, however, reverse power flows during mild, sunny weather will exceed the capacity of our network assets across many parts of the network, particularly in the low voltage (LV) network. When this occurs, we need to limit customers' solar output in the middle of the day to stop the network becoming overloaded. This 'solar curtailment' reduces the feed-in tariff benefits for solar customers and reduces the amount of low-cost green energy in the system for others.*"

The main component of the SA Power Networks proposed Customer Energy Resources (CER) integration expenditure is a program of targeted investments to add additional capacity in congested areas so that solar customers can continue to export, or feed in, their surplus energy to the distribution network.

Network Visibility

SA Power Network state that acquiring and processing voltage and other power quality data is now expected to be available from a faster rollout of smart metering, to efficiently manage network operations, increase CER hosting capacity and improve safety. SA Power Networks have forecast that $9.1 Million CapEx (5 years) is required for this activity.

Tariffs

The tariff structure proposed by SA power Networks are shown in Figure 9-12

Residential Time of Use | RTOU	**Default, Opt-out** Interval meter 0-30kW export capacity	Fixed	$/day	Fixed supply charge per annum.
		Fixed	$/day	Fixed metering charge per annum.
		Usage – Peak	$/kWh	12 hours per day not captured in the Off Peak or Solar Sponge windows.
		Usage – Off Peak	$/kWh	Six hour window of 12:00am – 6:00am.
		Usage – Solar Sponge	$/kWh	Six hour window of 10:00am – 4:00pm.
		Export Free – Solar Sponge Allowance	$/kWh	9kWh per day free of charge in six hour window of 10:00am – 4:00pm. If export between 10:00am – 4:00pm is less than 9kWh, the remainder of the free allowance rolls over to the next day, within a single billing period.
		Export Charge – Solar Sponge	$/kWh	Six hour window of 10:00am – 4:00pm. All export above 9kWh free allowance that occurs in the Solar Sponge window.
		Export Free – All other times	$/kWh	18 hours per day not captured in the Solar Sponge window.

Figure 9-12: SA Power Networks Proposed Tariff Structure adapted from [23]

9.6 Tasmania - TasNetworks (2024-29)

The TasNetworks submission [24] states that "*The distribution network was not designed for bidirectional power flows, high penetration of CER and active energy management by consumers. As CER uptake continues to grow, understanding and managing power flows and voltage regulation becomes more challenging. Sections of the network can become overloaded and congested, resulting in consumers being unable to connect new CER or use their existing CER to full capacity. Uptake of EVs may also result in increased overall consumption, maximum demand on the network and network complexity due to vehicle charging. In Tasmania, it is projected that the implementation of solar PV and household batteries will continue to grow and the uptake of EVs will accelerate towards the end of this decade. Current modelling suggests there is insufficient uptake to cause widespread network constraints in the 2024-2029 regulatory control period for TasNetworks and our customers. Therefore, TasNetworks proposes a steady and modest investment in enabling ongoing connection of CER and improving our visibility of the low voltage network.*"

Tariffs

The proposed low voltage tariff structure for TasNetworks is shown in Figure 9-13.

Network tariff	Network access	Charging parameters	Peak	Shoulder	Off-peak	Super off peak
TAS93 – Low voltage residential time of use consumption [default network tariff]	Daily service charge c/day	Time of use consumption charge c/kWh	Weekdays 07:00 to 10:00 and 16:00 to 21:00	✖	All other times	✖
TAS87 – Low voltage residential time of use demand	Daily service charge c/day	Time of use demand charge c/kW/day	Weekdays[33] 07:00 to 10:00 and 16:00 to 21:00	✖	All other times	✖
TAS97 – Low voltage residential time of use consumer energy resources (CER)	Daily service charge c/day	Time of use consumption charge c/kWh	Demand threshold applies when demand exceeds 8.5kW anytime			
			Weekdays 07:00 to 10:00 and 16:00 to 22:00	✖	All other times	Weekdays and weekends Midnight to 04:00

Figure 9-13: Proposed TasNetworks Low Voltage Tariff Structure adapted from [25]

The TasNetworks submission identifies that Tasmania has a relatively low penetration of solar PV installations compared to other jurisdictions and TasNetworks has not yet experienced widespread issues relating to the export of solar PV generation to the network. While solar PV capacity is expected to grow throughout the 2024-2029 regulatory control period and beyond, at this stage TasNetworks does not expect this to result in material issues (relating to the export of solar PV generation) that will drive network expenditure. This is because solar PV generation will in large part be absorbed by storage (for later use, such as in peak times) and increasingly by electric vehicles. Tasmania has a comparatively stable minimum (and base) demand. On this basis, TasNetworks is not proposing to introduce export tariffs in the 2024-2029 regulatory control period.

10 Conclusion

The Australian Energy Regulator (AER) commissioned the Australian Power Quality Research Centre (APQRC) at the University of Wollongong (UOW) to undertake research and data collection to explore the range of possible consumer benefits that may flow from improved management of supply voltage magnitudes including:

1. Reduced energy consumption (and associated reductions in carbon emissions).
2. Improved appliance lifespan.
3. Increased hosting capacity and reduced consumer energy resources (CER) curtailment.
4. Any other identified benefits.

The project sought to answer following questions:

1. Is it possible to effectively identify and estimate the ways that overvoltage can impact consumers?
2. Are there practical and efficient solutions available to address these impacts from a distribution network perspective beyond what is already performed?
3. Are there practical ways in which distribution networks could consider these impacts in their investment decisions when considering existing network functions and regulatory obligations?
4. What further research may be needed to improve the way these impacts are assessed over time?

Surveys of Jurisdictional Regulators and DNSPs to better understand their challenges and approaches to supply voltage management have also been carried out as part of the project.

10.1 Impact of Supply Voltage on Consumers

An Initial Findings Report was delivered in early May 2024. This report identified that there is compelling evidence that supply at voltage magnitudes above the nominal or rated voltage will lead to additional energy usage for residential consumers. Depending on the generation mix used to supply electricity, this may also result in additional carbon emissions. The Initial Findings Report also evaluated to the relationship between supply voltage magnitude and appliance loss of life. Here the available literature is more limited and compelling evidence of a relationship between supply voltage magnitude and appliance lifespan is restricted to loss of life for incandescent lighting devices as well as the electrolytic capacitors used in the switch mode power supplies that are present in large numbers of consumer electronics. In terms of impacts of supply voltage magnitude on CER, the evidence suggests that the economic impact is small at present and is unlikely to increase markedly in the near term.

DNSPs are obliged to maintain voltage within prescribed limits and consumer appliances cannot be expected to operate efficiently and as intended outside these values. Assurance that, and if necessary, enforcement to ensure, voltage magnitudes are kept within technical limits should be a requirement for all DNSPs. While maintaining voltage magnitudes within technical limits must be the starting point, it is important to note that consumer impacts and benefits begin to accrue as soon as the supply voltage magnitude moves away from the nominal or rated voltage. Put another way, consumer benefits may be available even if supply voltage magnitudes are kept within the allowable voltage range.

Survey results showed that two thirds of DNSPs identified equipment damage or loss of life as an impact of poor voltage regulation on consumers while one third identified additional energy consumption as an impact.

10.2 Network Options to Better Manage Supply Voltage Magnitudes

The Initial Findings Report identified that there are many solutions available to DNSPs to better manage supply voltage magnitudes. These solutions include adjustment of network planning and operating strategies through to technology solutions. Indications are that supply voltage magnitudes are decreasing as the lowest cost strategies for reduction, such as zone substation float voltage adjustment and distribution transformer tap position correction, have been implemented. Given that many of these low-cost solutions have now been implemented, further improvements or management strategies are likely to require significantly higher cost solutions.

10.3 Regulation and Regional Challenges

The Initial Findings Report provided a summary of present technical standards and regulation for supply voltage magnitudes across the various jurisdictions in Australia and provided an indication of challenges that may be experienced in relation to better management of supply voltage management in different regions.

With respect to standards and technical regulation for supply voltage magnitudes, it was identified that there is some inconsistency in the technical requirements across different state jurisdictions. It was also found that few jurisdictions have active requirements in relation to reporting performance and/or frameworks to penalise/incentivise DNSPs to better manage of supply voltage magnitudes in their networks.

With respect to regional challenges, the following were identified as being the most relevant:

- **Network load characteristics including energy supply fuel mix** – factors such as legacy planning processes/standards and traditional energy supply fuel mix will have significant implications for management of supply voltage magnitudes as the electricity supply systems transitions to higher levels of electrification and higher levels of CER integration.

- **Level of solar PV generation penetration** – solar PV generation will lead to some quantum of voltage rise which in turn can result in challenges for maintaining appropriate supply voltage magnitudes. The quantum of voltage rise is a function of both the amount of solar PV generation and the characteristics of the network.

- **Regulatory environment** – the regulatory environment in which a DNSP operates will influence the way in which it undertakes management of supply voltage magnitude. At present, there is a lack of consistency across jurisdictions in terms of technical standards, assessment and reporting requirements, and reward/penalty frameworks.

- **Access to data** - in some cases, the ability of DNSPs to manage supply voltage regulation, particularly in an environment of increasing CER, is hampered by a lack of access to data that enables visualisation and control of network performance.

10.4 Algorithms to Estimate Benefits of Better Management of Supply Voltage Magnitudes

Algorithms have been developed to estimate the impact of supply at voltage magnitudes above the nominal value for both increased energy consumption as well as decreased appliance lifespan. The following assumptions are used for algorithm development:

- Performance at the nominal voltage, 230 V is taken as the origin or zero value for all algorithm development. Consumer benefit accrues as the supply voltage is brought closer to 230 V.
- The algorithms only consider the benefits of reducing voltages above 230 V. This approach is justified as evidence to date suggests that the greatest impact on consumers is due to voltage magnitudes above the nominal, and all evidence suggests that Australian LV supply networks are characterised by voltage magnitudes at the upper end of the allowable range, with undervoltage concerns being limited to date.
- The models rely on data related to residential load mix, price of electricity, appliance cost, appliance expected lifespan. Some of this data is available in the Residential Baseline Survey while in other cases it has been estimated. These estimations may vary across jurisdictions and will require consideration before application.
- The algorithm provided which relates supply voltage magnitude to appliance loss of life is preliminary and subject to the limitations outlined in Section 10.6 below. As such, this algorithm is provided for illustrative purposes and quantitative values have not been calculated.

While the investigation that have been undertaken in this report primarily focus on residential loads, similar concepts can be applied to commercial and industrial loads as well as network equipment.

10.5 Estimation of the Consumer Benefit

With respect to estimating the impact of supply at voltages above the nominal value, there appears to be sufficient data available to characterise the relationship between supply voltage magnitude and energy consumption for the devices which comprise the domestic load. Application of the algorithm outlined in this report indicates that the consumer benefit of reducing voltages to closer to the nominal value of 230 V on energy consumption and in turn electricity bills is in the tens of dollars per dwelling per annum ongoing.

Given the limitations of the algorithm for calculation of the benefit

Given the limitations of the algorithm, a quantitative estimate of the consumer benefits of better management of supply voltage magnitudes as it applies to loss of life in consumer appliances has not been calculated in this report.

While the algorithms developed in this report provide benefits which are assessed based on the ability to supply all locations at 230 V. Both the physics and the cost-effective design of electricity supply networks precludes supply at 230 V at all locations. There will always be locations where the supply voltage magnitude must be higher while there will be others where the supply voltage magnitude will be lower. As such, the estimates provided may need to be adjusted to better reflect the actual capabilities of electricity supply networks which in turn may require access to additional supply voltage magnitude data.

10.6 Limitations and Further Research

With respect to the relationship between supply voltage magnitude and appliance loss of life, considerably more research is required before a comprehensive and robust algorithm to estimate the benefits of better management of supply voltage magnitude can be developed. The research outcomes required includes:

- Better understanding of the sensitivity of the full range of components (e.g. transformers and electronic switching components) that make up appliances to supply voltage magnitude.
- Better understanding of appliance turnover and failure rates.
- Better understanding of consumer sentiment to appliance replacement/renewal, i.e. if an appliance fails but a consumer is happy to replace it with a newer/upgraded model is the impact relevant?
- Better understanding of the relationship between supply voltage magnitude and loss of life for appliances that are predominately motor based.

Each of the algorithms requires supply voltage magnitude data as an input. Access to supply voltage magnitude data is much more readily available to some DNSPs than others. Consideration should also be given to development of mechanisms that allow DNSPs to cost-effectively access the data required to ensure adequate visibility of LV voltage performance and as input to the algorithms for calculation of the benefit of improved supply voltage management detailed in this report.

10.7 Suggested Actions

All evidence suggests that there will be ongoing consumer economic benefits of reducing supply voltage magnitudes with the benefit being significant for consumers supplied at voltage at the upper end of the allowable voltage range. These benefits may accrue to large values when applied across large jurisdictions or nationally and may include significant reductions in carbon emissions (depending on the generation fuel mix). Consideration should be given to the following:

- Development and implementation of a framework that can be used by DNSPs to estimate the consumer impact associated with the additional energy consumption related to supply voltage magnitude.
- Development and implementation of a framework that can be used by DNSPs to estimate the consumer impact associated with the relationship between supply voltage magnitude and loss of appliance lifespan.
- Development of a framework to allow the above to be incorporated into DNSP regulatory submissions.
- Enabling actions to allow DNSPs better access to supply voltage magnitude data.
- How the research required to develop a more robust algorithm to estimate the relationship between supply voltage magnitude and appliance lifespan can be undertaken. This may include engagement with appliance OEMs or organisations managing warranty claims and repair to better understand appliance failure rates and mechanisms.

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[23] SA Power Networks, "*Attachment 18 - Tariff Structure Statement Part A 2025-30 Regulatory Proposal*", 2024.

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A Appendix A: Additional Energy Consumption Case Studies

This case study provides indication of how the additional energy consumption algorithm could be applied to calculate a direct benefit of better management of supply voltage magnitudes for consumers. The case study utilises RBS data for Victoria for 2023. Using the data shown in Figure 4-2 in conjunction with the RBS data it is possible to calculate the additional energy usage per dwelling per annum for any given supply voltage magnitude. The output of this calculation is shown in Figure A-1.

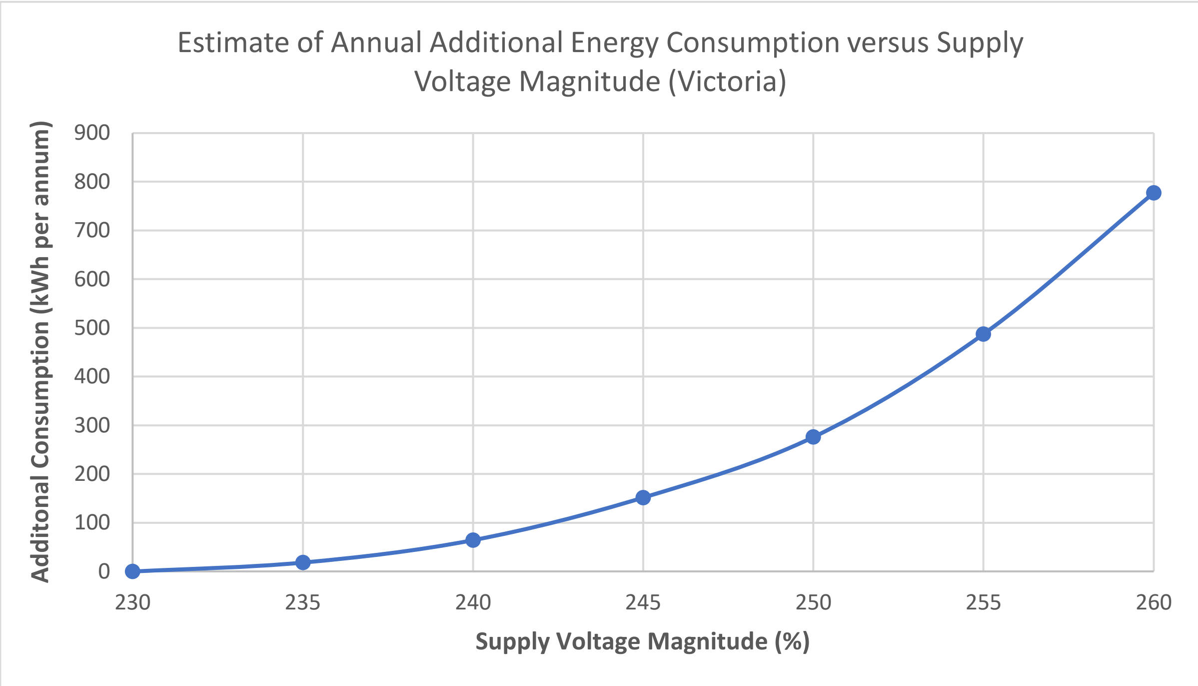

Figure A-1: Estimate of per Dwelling Additional Energy Consumption (Victoria, 2023 Data)

Calculation of a value in dollars for each supply voltage magnitude is as simple as multiplying the data shown in Figure A-1 by the cost of electricity. As an example, Figure A-2 shows the single dwelling consumer benefit of reducing supply voltage magnitude for additional energy consumption based on an electricity price of 18c/kWh and 24 c/kWh. These figures are based on the retail price of electricity being between 25c/kWh and 35 c/kWh. Give that approximately 36% of the price of electricity consists of fixed network charges, the remaining energy consumption related component of the retail price is between 18c/kWh and 24 c/kWh.

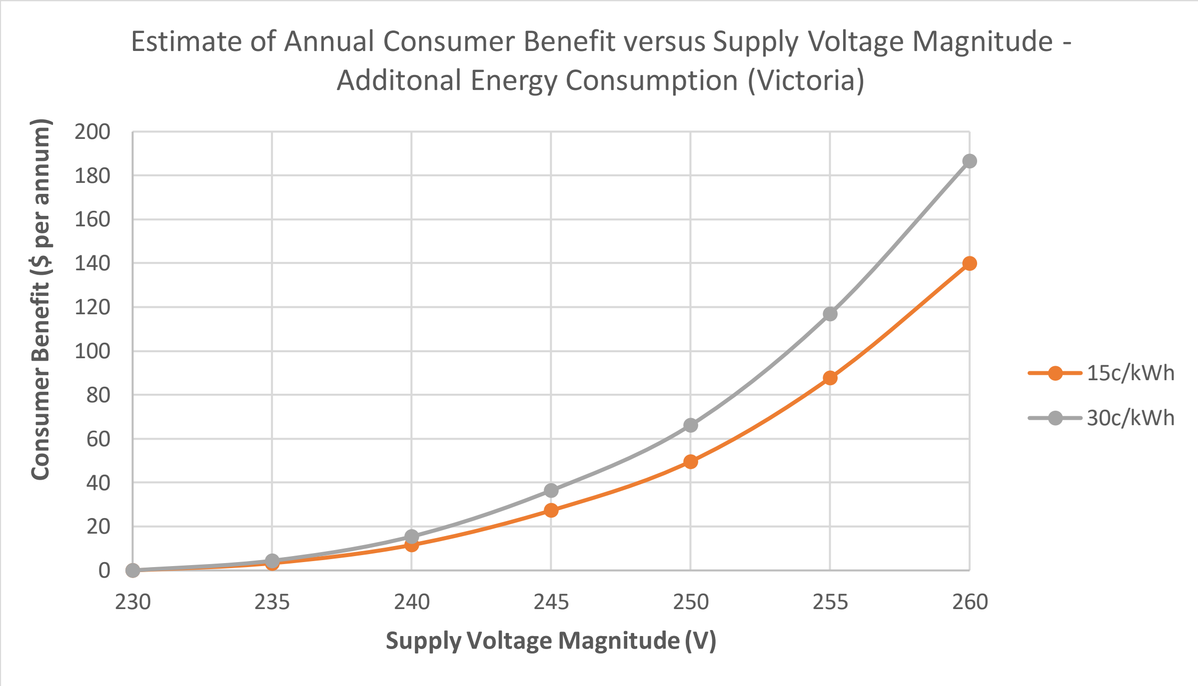

Figure A-2: Single Dwelling Consumer Benefit of Reduction in Supply Voltage Magnitude based on Energy Consumption

B Appendix B: Appliance Lifespan Reduction Case Study – Incandescent Lighting

This case study demonstrates how the loos of life algorithm for incandescent lighting can be applied to calculate the consumer benefit of reducing supply voltage magnitudes. The residential baseline survey provides data for consumer device stock (i.e. numbers of devices) on a state-by-state and year-by-year basis. For the purposes of this case study, data for Victoria for 2023 has been utilised. A nominal cost for each lighting device type has also been selected to be $2 per lamp. The rated life of each lighting technology is based on information on packaging. The relevant data for the algorithm is presented in Table B-1. Based on this data, the annual consumer benefit for a single dwelling calculated using the algorithm is shown in Figure B-1.

Table B-1: Data for Incandescent Lighting Loss of Life Algorithm

Lamp Type	Number per Dwelling	Initial Cost ($)	Rated Life (Years)
MV halogen	1.8	2	1.52
MV incandescent	1.3	2	0.76

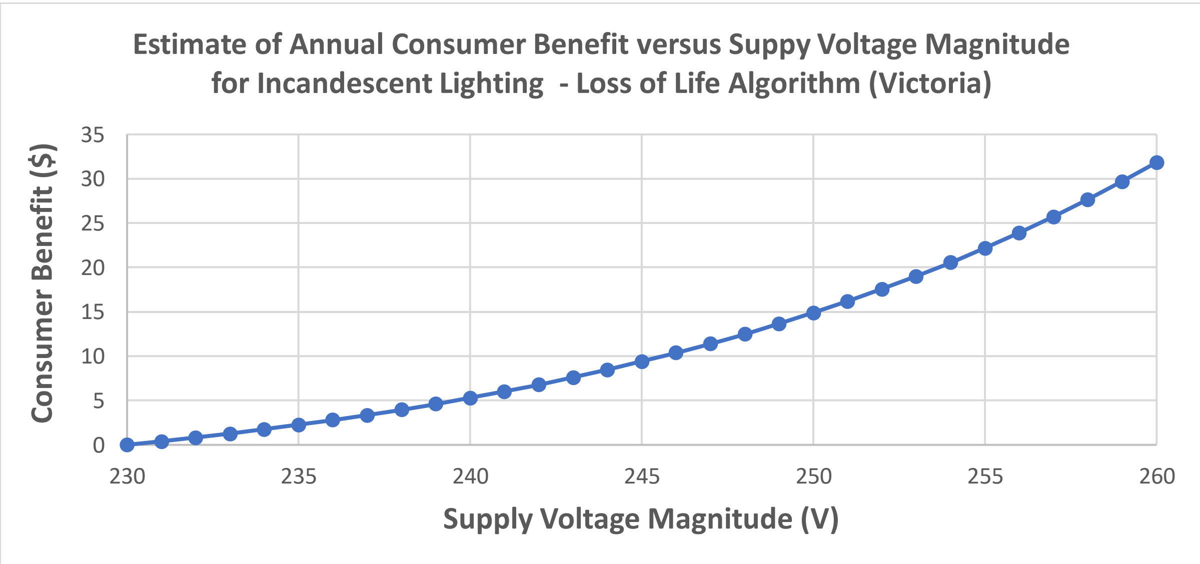

Figure B-1: Single Dwelling Estimated Annual Consumer Benefit based on Incandescent Lighting Loss of Life (Victorian Consumers for 2023)

If an average voltage of 242 V is considered, Figure B-1 indicates that the consumer benefit of reducing the voltage to 230 V is approximately $7 per dwelling per annum.