AUGMENTATION

NORTHERN MURRAY HARMONICS MANAGEMENT

PAL BUS 3.08 – PUBLIC

2026–31 REGULATORY PROPOSAL

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1. Overview

Customers within the Northern Murray area of our network are receiving harmonic distortions in their voltage levels. This is driven by variable speed drive systems, which control the speed and torque of AC motors, such as those found in irrigation pumps. A significant portion of industry within the Northern Murray area relies on irrigation from pumping infrastructure, such as farming and agriculture.

The voltage distortions are non-compliant with the Electricity Distribution Code of Practice (EDCoP), National Electricity Rules (NER) and Australian Standards, which require us to maintain total harmonic distortion in voltage (THDv) below 6.5 per cent. Voltage distortion has reached up to 20 per cent for customers in the Northern Murray area. Voltage distortion can negatively impact the lifecycle and function of customer assets, which customers have reported to us can disrupt production, reduce appliance lifespan and increase labour costs.

We are currently non-compliant at the end of long feeders, and we were alerted to the non-compliance through customer complaints and data sharing. It is not standard industry practice to monitor harmonic compliance at a feeder level.

Typical resolutions to harmonic distortions that we would provide, including customer harmonic management, reactive customer management, and pole top capacitor optimisation have been effective in addressing some distortions, but ineffective at addressing all distortions.

Our remediation plan has been shared with the Essential Services Commission, noting that our remediation plan is consistent with our business case proposal.

We are currently working with industry on developing a standard to address harmonic distortions on feeders.

This business case proposes to install low voltage active harmonic filters on seven feeders to address non-compliant harmonic levels on our network.

The capital expenditure forecast of our preferred option is shown in table 1 below.

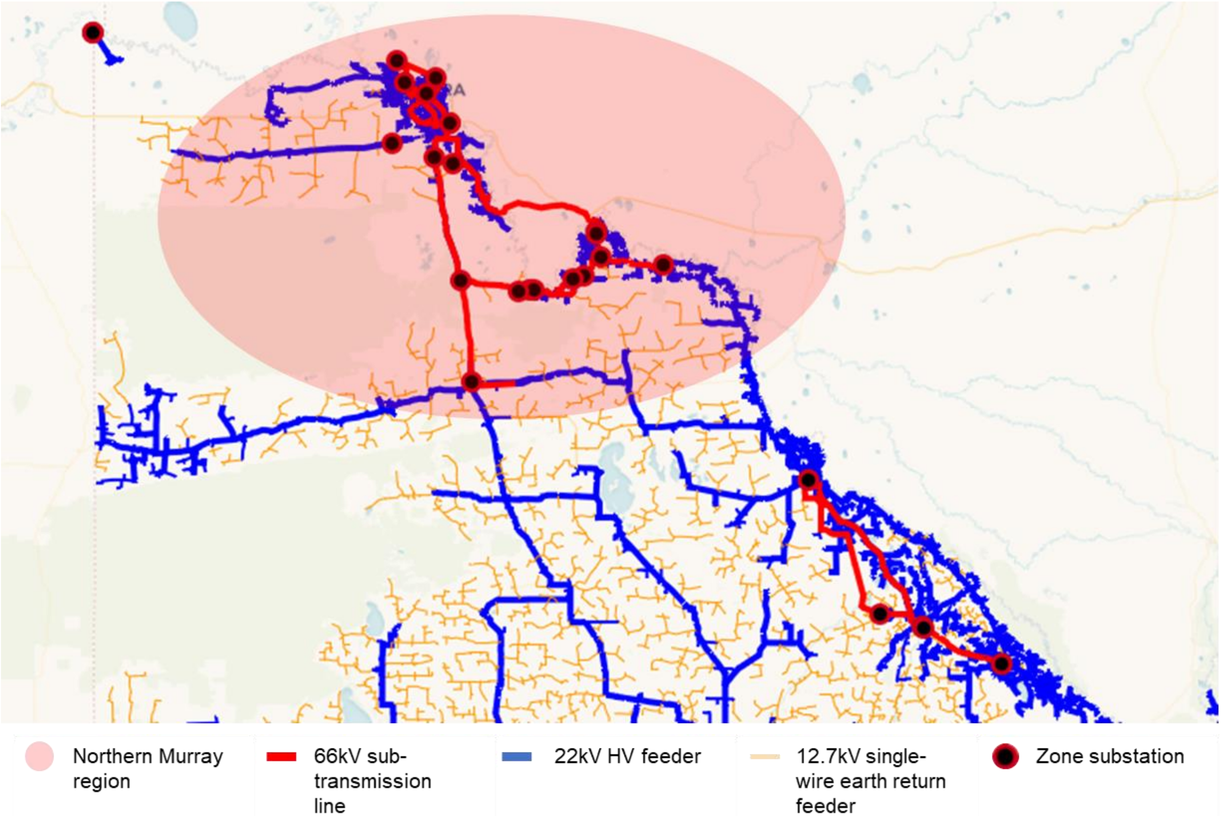
TABLE 1 EXPENDITURE FORECAST FOR PREFERRED OPTION ($M, 2026)

PROJECT	FY27	FY28	FY29	FY30	FY31	TOTAL
Install low voltage (LV) active filters on seven feeders	2.4	2.9	2.4	-	-	7.7

2. Background

The Northern Murray region is located near the New South Wales border and covers the north-west part of Victoria along the Murray River from Nyah to the South Australian border as shown in figure 1. The region is essential to Victorian agriculture, producing 53 per cent of Victoria's gross value of agricultural production.[1]

FIGURE 1 NORTHERN MURRAY IRRIGATION REGION



Note: Includes customer-owned zone substations

Irrigation farmers in the region use a considerable number of variable speed drives (VSDs) to pump water from the Murray River. VSDs control the speed and torque of AC motors, which control the rate that water is pumped.

VSDs convert AC voltage input into DC voltages used by the motor, which then increases the harmonic levels experienced on the network. VSDs cause voltage harmonic distortions, which impact the stability of voltage levels that we can deliver to our customers.

Technology development has seen a shift from standard motorised equipment towards VSDs over time. Standard motorised equipment does not impact harmonics, but VSD equipment does.

1 The Mallee Catchment Management Authority, Victorian Mallee Irrigation Region Land and Water Management Plan 2020-29, 2020, p.14.

3. Identified need

Harmonic distortions in voltage levels supplied to customers arise from the presence of VSD loads such as irrigation pumps. Voltage distortion in the Northern Murray region is high due to the high prevalence of VSD loads that pump water from the Murray River to irrigate crops.

Under the EDCoP, NER and Australian standard, we are required to maintain the total harmonic distortion in voltage (THDv) below the compliance limit of 6.5 per cent in the medium voltage (MV) network.[2] This is to ensure that our customers receive a stable voltage supply that enables efficient use of electricity.

As outlined below, we are currently non-compliant at the end of long feeders.

The identified need, therefore, is to reduce voltage harmonic distortion on sections of our network in the Northern Murray area to within compliant limits of 6.5 per cent as prescribed under the EDCoP.

3.1 Harmonic levels are non-compliant in the Northern Murray area

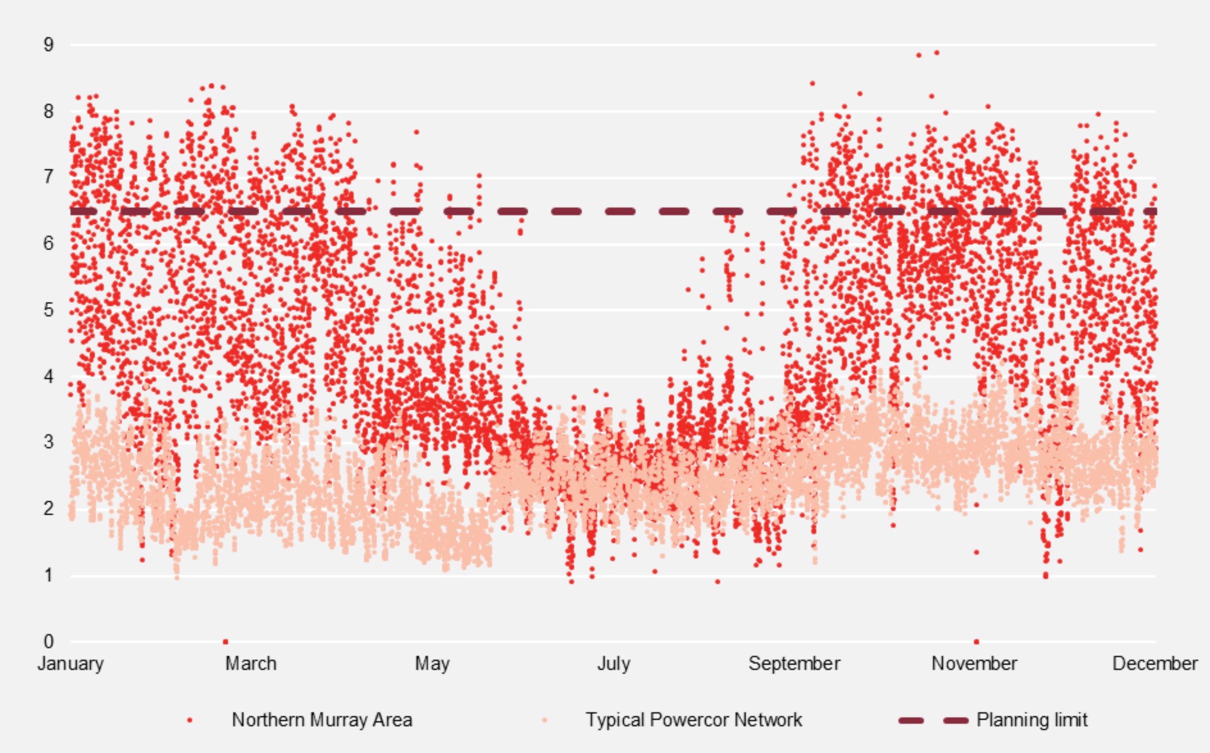
In the Northern Murray region of north-west Victoria, voltage harmonic distortion is non-compliant during the irrigation season. In some instances, harmonic distortion levels have exceeded allowable limits by up to three times. This non-compliance is attributable to the extensive pumping infrastructure used to source irrigation water from the Murray River, which sustains the region's significant agricultural production.

Total voltage harmonic distortion has reached 20 per cent in sections of the network within the Northern Murray region, whereas harmonic distortion typically remains below 5 per cent in other areas. Areas with high harmonic levels are typically located at the end of long feeders.

The spread of harmonics at a typical zone substation and one located in the Northern Murray region are depicted below in figure 2. The harmonic level of a typical zone substation remains consistently low and stable across seasons, while the typical Northern Murray zone substation consistently experiences harmonic levels above 6.5 per cent due to the extensive use of pumping loads for agricultural production.

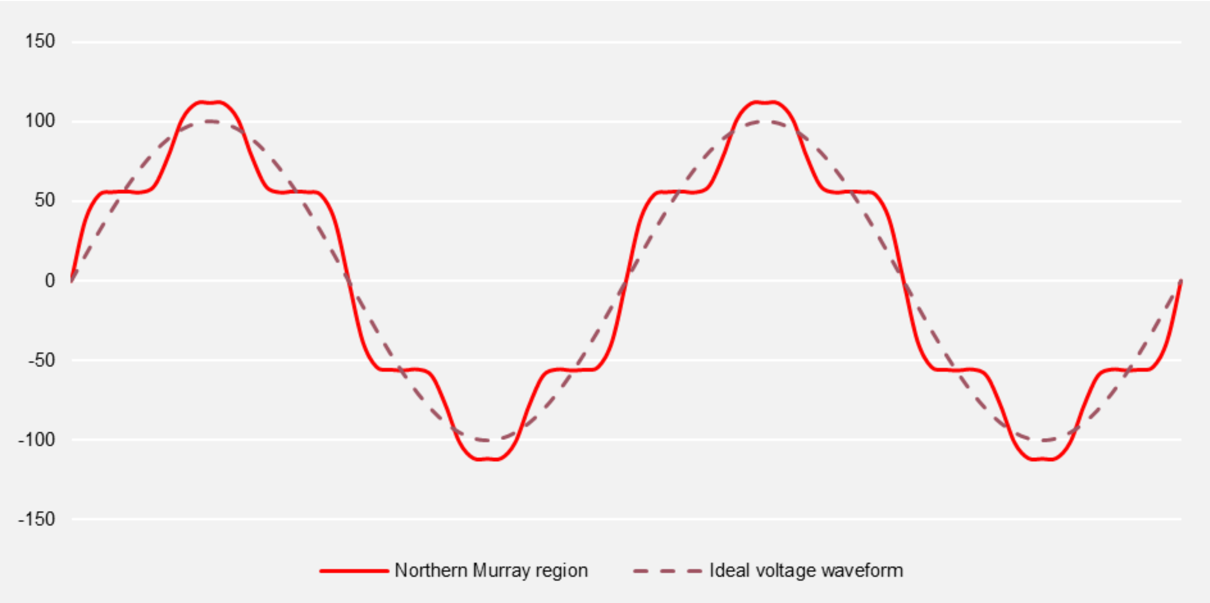
2 Electricity Distribution Code of Practice clause 20.6.1, and National Electricity Rules clause S5.1a.6 and AS/NZS 61000.3.6:2001 table 2.

FIGURE 2 RECORDED HARMONIC LOAD RANGES IN 2023 (THDV %)



An example of the distorted voltage waveform experienced by customers in the Northern Murray region is provided below in figure 3 below. This waveform is compared to a stable waveform observed in other sections of our network.

FIGURE 3 VOLTAGE WAVEFORM DISPARITY (VOLTAGE %)



Harmonic levels in the Northern Murray region have been increasing over time with the increasing take up of VSDs as technology shifts towards VSDs from standardised motorised equipment.

3.1.1 Monitoring harmonic levels on feeders is not standard industry practice

Harmonic levels at all of our zone substations are currently maintained at compliant levels. Compliant harmonic levels at zone substations can be maintained because the power quality produced close to transformers is strong but gradually declines as power flows further away from the transformer.

We have been receiving complaints from customers with non-compliant harmonic levels. These customers are typically located towards the end of feeders. It is not standard industry practice to monitor harmonic levels at the end of feeders because no distributor currently has the capability to capture this data. We are only aware of non-compliant harmonic levels due to customer complaints and customers sharing their data with us.

3.1.2 Our remediation plan to return harmonic levels to compliance with the Essential Services Commission

We have notified the Essential Services Commission of harmonic non-compliance within our network and have shared our remediation plan to achieve long-term compliance by 2030. Our multi-year remediation plan includes least-cost network augmentation that is necessary to bring harmonic distortion levels in the Northern Murray region back within compliance limits, and is consistent with this business case.

We currently use reactive customer engagement, customer collaboration and pole-top capacitor optimisation to mitigate poor harmonic levels across our network.

While these approaches have been able to mitigate harmonic distortion across the network and minimise the necessity for additional investment in several locations, they have not been sufficient to address five additional supply areas experiencing elevated harmonic distortion levels.

Alternative feeder-level solutions are available to alleviate harmonic distortion in these regions and sustainably maintain compliance levels. However, there is no current industry standard for the remediation of non-compliant harmonics on feeders.

We are currently working on developing an industry standard for the implementation of harmonic management on feeders. Implementation of any feeder-based solution in the current regulatory period will be delayed while we work with industry to finalise the standard and ensure that our implementation complies with the standard.

3.1.3 Non-compliance is subject to civil penalties

Since October 2022, the Essential Services Commission (ESC) of Victoria has introduced Civil Penalties for distributors who are non-compliant with the EDCoP.[3] Non-compliant harmonic levels are considered a type 2 breach and is subject to civil penalty of up to $1.5 million.

3.2 Harmonic levels are negatively impacting customers

Harmonic distortions in the electricity system cause motors in VSD machinery to consume more electricity to operate. This leads to increasing electricity usage and costs for customers.

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[3] Essential Services Commission, Electricity Distribution Code of Practice, clause 20.6 and schedule 1 and schedule 6

It also means that the cooling systems that act to control the temperature of motors have to work harder to maintain stable operating temperatures. When harmonics become high enough, the cooling systems in a VSD can fail, which will lead to the motor burning out and malfunctioning.

Asset failure and malfunction can lead to production losses, equipment replacement costs and additional labour costs. Equipment can often be highly valuable to our customers.

3.2.1 Stakeholders support investment to remediate non-compliant harmonic levels

During our engagement program, our customers emphasised that harmonics were having a significant impact on the performance and lifespan of industrial machinery, particularly in critical sectors such as agriculture, water utilities and manufacturing.

As part of our Test and Validate engagement program, we tested whether stakeholders would support investment to improve harmonics in the Northern Murray region. Stakeholders were supportive of efforts to address harmonic issues.

A water utilities customer reflected that investment to manage harmonics in the region is critical.[4]

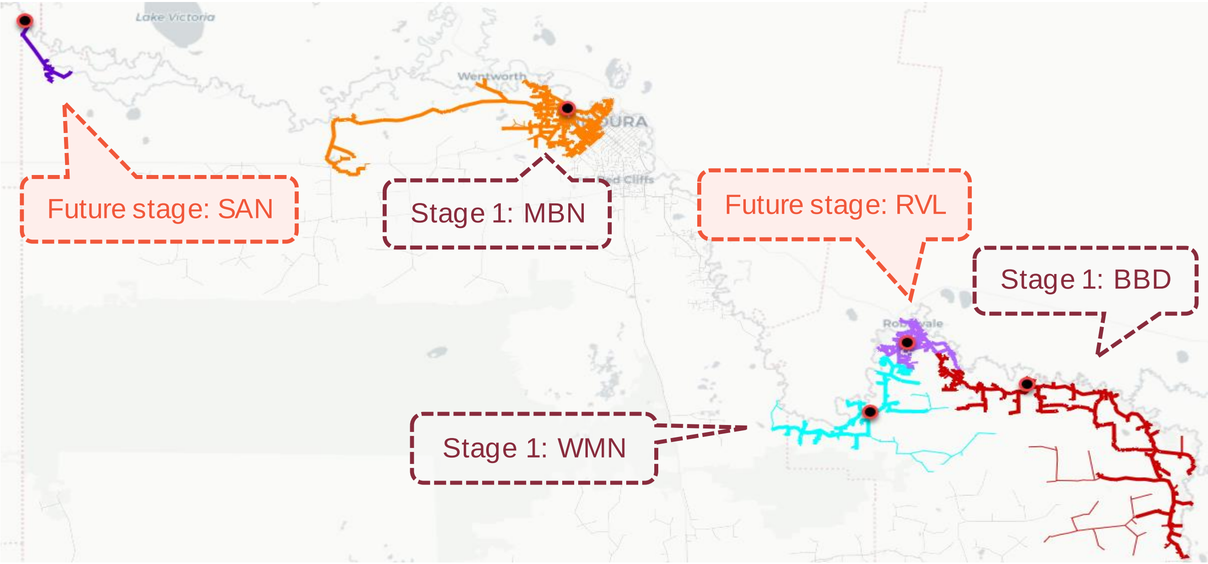
> *"a critical investment for our operations, especially given the sensitivity of our equipment. Its not just about protecting assets; its about preventing costly downtime."*

4 Forethought, Test and Validate: Commercial and Industrial Customers Engagement, 2024, p. 36

4. Option analysis

The supply areas of the zone substations that continue to experience harmonic distortions above the planning limit are highlighted in figure 4. In the 2026-31 regulatory period, we are concentrating on remediation at the Boundary Bend (BBD), Merbein (MBN), and Wemen (WMN) zone substations, where harmonic distortion levels reach up to 20 per cent, exceeding the allowable limits by threefold. Subsequent stages will remediate the emerging harmonic challenges in the area covered by the Robinvale zone substation (RVL) and South Australia North (SAN) feeder.

FIGURE 4 STAGED APPROACH TO ADDRESS HARMONICS



Several options were considered to address the identified need of remediating harmonic levels to within compliant levels. Broadly, our options consider the merits of installing various types of harmonic filters that have the potential to improve harmonic compliance levels.

Four credible options were assessed relative to an existing status quo base case. Each option assesses in-feeder options from different harmonic mitigation techniques.

Several options were not considered credible to address the identified need, including reactive customer engagement, customer harmonic management and pole-top capacitor optimisation. These options have already been implemented and have been insufficient to address the identified need. Further information on our current implementation of these solutions is described in appendix A.

As a compliance requirement, the selection of fault level mitigation options would typically be determined on a least-cost, technical feasibility basis. However, there are also benefits delivered to customers from reductions in line losses incurred, which we have valued in our options assessment.

A summary of the credible options considered is presented in table 2 below.

TABLE 2 OPTIONS SUMMARY ($M, 2026)

OPTION	PV COSTS	PV BENEFITS	NET BENEFIT
Option one: status quo	Not credible	Not credible	Not credible
Option two: active harmonic filters	-5.3	0.3	-4.9
Option three: passive harmonic filters	-5.4	0.3	-5.0
Option four: SOFIA harmonic filters	-6.3	0.3	-6.0
Option five: static synchronous compensators (STATCOM)	-7.8	0.3	-7.5

4.1 Option one: status quo

Option one maintains the status quo approach of continuing to implement the three approaches we have used to manage harmonic distortions, discussed further in appendix A. As the benefits of all three approaches have been exhausted, customers will experience increasing harmonic distortion power quality issues including:

- additional motor losses and lifetime reduction of customers assets
- asset failure or malfunction due to high harmonics
- production losses and extra labour costs.

We will also remain non-compliant with our obligations to provide stable harmonic levels for our customers, and will be at risk of financial penalties imposed by the ESC.

Therefore, maintaining the status quo is not credible as network harmonic level remains non-compliant with no plan to address these further.

4.2 Option two: installation of low voltage active harmonic filters

This option involves the installation of low voltage (LV) active harmonic filters.

LV active filters inject counteracting currents that offset harmonic distortions in the network to reduce voltage harmonic distortion.

Under option two, 13 LV active filters would be installed across three feeders at the Merbein (MBN), Boundary Bend (BBD) and Wemen (WMN) zone substations. This would have the impact of reducing harmonic levels to within the prescribed limit of THDv 6.5 per cent.

A high voltage (HV) capacitor bank will also be installed on our BBD21 feeder to improve the harmonic impedance of the network and cost-effectively reduce voltage harmonic distortion.

In addition to receiving compliant harmonic levels, customers would derive additional benefits through a reduction in energy at risk relative to the status quo case due to a reduction in line losses associated with the additional feeders.

The present value of expenditure required to deliver this option is presented in table 3 below.

TABLE 3 OPTION TWO: NPV OF COSTS AND BENEFITS ($M, 2026)

OPTION TWO	PV COSTS	PV BENEFITS	NET BENEFIT
Option two: LV active harmonic filters	-5.3	0.3	-4.9

4.3 Option three: installation of passive harmonic filters

This option involves the installation of LV passive harmonic filters.

Passive harmonic filters enhance the harmonic impedance characteristics to improve voltage harmonic distortion. Passive harmonic filters target the remediation of specific harmonic frequencies and are effective for improving specific harmonics but require a large installation footprint.

Under option three, seven LV active filters would be installed across three feeders connected to the MBN, BBD and WMN zone substations. This would have the impact of reducing harmonic levels to within the prescribed limit of THDv 6.5 per cent.

In addition to receiving compliant harmonic levels, customers would derive additional benefits through a reduction in energy at risk relative to the status quo case due to a reduction in line losses associated with the additional feeders.

The present value of expenditure required to deliver this option is presented in table 4 below.

TABLE 4 OPTION THREE: NPV OF COSTS AND BENEFITS ($M, 2026)

OPTION THREE	PV COSTS	PV BENEFITS	NET BENEFIT
Option three: LV passive harmonic filters	-5.4	0.3	-5.0

4.4 Option four: installation of SOFIA harmonic filters

This option involves the installation of harmonic filters from the company SOFIA.

SOFIA harmonic filters perform intelligent adaption that undertakes voltage-controlled switching of capacitors to filter out currents from a power system.

SOFIA harmonic filters measure the voltage harmonic level within a feeder and act to reduce it. The filters do not create resonance, and reactive power use and losses are low. They can also enhance the steady-state voltage at the end of the feeders but require a large installation footprint.

Under option four, seven SOFIA harmonic filters would be installed across three feeders connected to the MBN, BBD and WMN zone substations. This would have the impact of reducing harmonic levels to within the prescribed limit of THDv 6.5 per cent.

A HV capacitor bank will also be installed on our BBD21 feeder to improve the harmonic impedance of the network to reduce the voltage harmonic distortion.

In addition to receiving compliant harmonic levels, customers would derive additional benefits through a reduction in energy at risk relative to the status quo case due to a reduction in line losses associated with the additional feeders.

The present value of expenditure required to deliver this option is presented in table 5 below.

TABLE 5 OPTION FOUR: NPV OF COSTS AND BENEFITS ($M, 2026)

OPTION FOUR	PV COSTS	PV BENEFITS	NET BENEFIT
Option four: SOFIA harmonic filters	-6.3	0.3	-6.0

4.5 Option five: installation of static synchronous compensators

A static synchronous compensator (STATCOM) is a fast-acting device that provides reactive power support to the network to control the voltage at the point of connection. STATCOMs mitigate harmonics and are effective in enhancing voltage performance. However, STATCOMs are relatively expensive pieces of equipment.

Under option five, seven STATCOMs would be installed across three feeders connected to the MBN, BBD and WMN zone substations. This would have the impact of reducing harmonic levels to within the prescribed limit of THDv 6.5 per cent.

In addition to receiving compliant harmonic levels, customers would derive additional benefits through a reduction in energy at risk relative to the status quo case due to a reduction in line losses associated with the additional feeders.

The present value of expenditure required to deliver this option is presented in table 6 below.

TABLE 6 OPTION FIVE: NPV OF COSTS AND BENEFITS ($M, 2026)

OPTION FIVE	PV COSTS	PV BENEFITS	NET BENEFIT
Option five: STATCOM	-7.8	0.3	-7.5

5. Preferred option

The preferred option for the 2026–31 regulatory period is option two, installing seven LV active harmonic filters at the end of feeders across MBN, BDD and WMN in the Northern Murray area.

This option is preferred because it will facilitate the achievement of compliant harmonic outcomes for customers at the lowest cost and the highest net benefit. Without this augmentation, we would not be compliant with our obligations to maintain stable power quality for our customers through the 2026–31 regulatory period.

A detailed summary of where the LV active harmonic filters will be installed across our network is described in table 7 below.

TABLE 7 PREFERRED OPTION: LV ACTIVE FILTER INSTALLMENT

ZONE SUBSTATION	LV ACTIVE HARMONIC FILTER FEEDER LOCATION
MBN	One 500-amp (A) (200 kVA) LV active filter at MBN31
BBD	Six 500A (200 kVA) LV active filters, including one at BBD 13, two at BBD 14 and three at BBD 21
WMN	Six 500A (200 kVA) LV active filters, including two at WMN bus, one at WMN 14 and three at WMN 21

The deployment of LV active harmonic filters under each option will require procurement, testing, deployment and refinement to ensure they are delivering the benefits we expect.

We are currently working on developing an industry standard for the implementation of harmonic management on feeders. Implementation in the current regulatory period will be delayed while we work with industry to finalise the standard and ensure that our implementation complies with the standard.

The capital expenditure required to deliver the preferred option is shown in table 8 below.

TABLE 8 EXPENDITURE FORECAST FOR PREFERRED OPTION ($M, 2026)

CAPITAL EXPENDITURE	FY27	FY28	FY29	FY30	FY31	TOTAL
Install LV active harmonic filters	2.4	2.9	2.3	-	-	7.7

A Description of current harmonic management approaches

We have observed significant variance in harmonic levels between the end of long feeders and the zone substation in the Northern Murray region. While harmonics tend to be low at the zone substation bus, they escalate notably towards the end of feeders. Although conventional harmonic filters installed at zone substations can mitigate harmonics at the zone substation level, they often fall short in addressing the elevated harmonic levels at the feeder's termination point. This discrepancy primarily stems from the high impedance characteristic of the feeder.

Feeder-based solutions that target and attenuate harmonics at the end of feeders are prudent for effective harmonic reduction in these circumstances. By directly addressing the impedance challenges inherent in the feeder topology, these solutions offer a more tailored and efficient means of harmonics management in the Northern Murray region.

Today, we actively implement three approaches to harmonic management. These approaches are effective in reducing harmonic distortions but are insufficient to bring distortions with the prescribed limit under the EDCoP.

5.1.1 Approach one: reactive customer engagement

We receive approximately five to six customer complaints annually concerning harmonic issues. Remedying complaints related to harmonics is significantly more expensive compared to handling other power quality complaints due to their inherent complexity. Resolving harmonic-related issues locally is often challenging and, in many cases, not feasible due to their network-wide nature.

Customer impacts observed in the Northern Murray area include:

- failure of VSD cooling systems, leading to pumping shutdowns
- malfunction of customer appliances
- premature failures of VSD drives.

We have limited options to respond to these challenges but have applied the following novel mitigations:

- installing local generation on sensitive equipment to provide a cleaner power supply
- implementing permanent Uninterruptible Power Supply (UPS) systems to supply sensitive circuits.

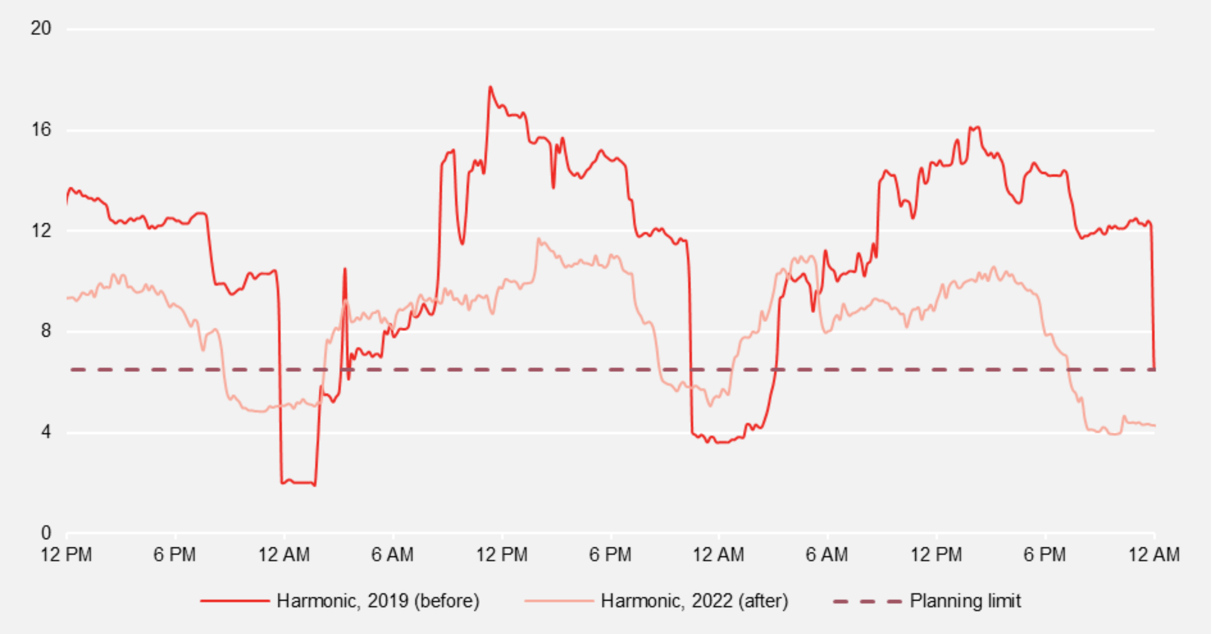
The Select Harvest case study in Appendix B provides further detail on these mitigations.

5.1.2 Approach two: customer harmonic management

We have initiated a multi-year customer compliance monitoring program aimed at identifying customers whose harmonic currents exceed the limits specified in table 5 of the EDCoP. Upon identification of non-compliance, we notify customers in writing, alerting them to the issue, and collaborate with them to rectify levels and return them to compliant levels. This ongoing process involves data logging and targeted interventions to address site-specific harmonic challenges.

While this program has shown promising results on certain feeders, as depicted in figure 5, the magnitude of levels means that even achieving full compliance with participating customers is insufficient to bring harmonic levels within the prescribed limits for the majority of feeders.

FIGURE 5 IMPROVEMENT IN HARMONICS LEVEL BY CUSTOMER HARMONIC MANAGEMENT (THDV %)

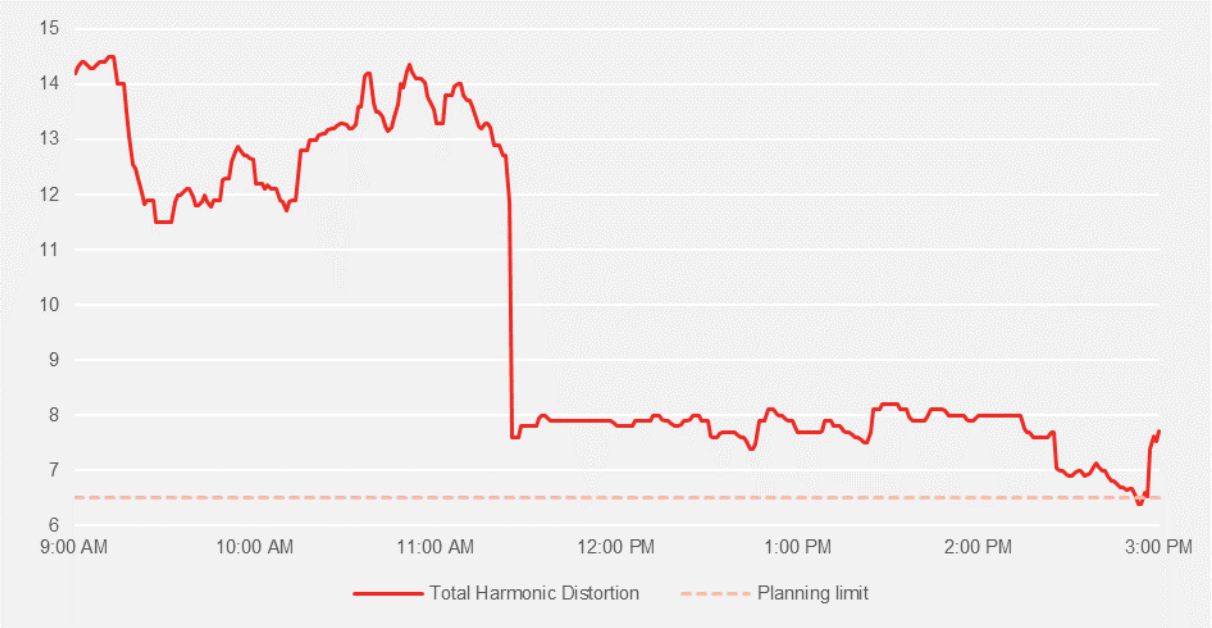


5.1.3 Approach three: pole top capacitor optimisation

In addition to addressing customer site resolutions, we conducted harmonic modelling of three zone substations where voltage harmonic distortion levels are notably elevated. The modelling results suggest that optimising the pole top HV capacitors could yield further improvements in harmonic distortion within certain feeders.

We have achieved significant success in this initiative, particularly with the Wemen feeder WMN21, where harmonic levels were reduced by approximately five per cent during optimisation. This is illustrated in figure 6, where the THDv percentage falls after the pole capacity is optimised at approximately 11:20am. However, while this option has proven effective in specific areas, it has fallen short of fully restoring compliance across remaining areas. This option not only reduces the overall need for harmonic filters but also underscores our commitment to finding the most cost-effective pathway to compliance.

FIGURE 6 IMPROVEMENT IN CAPACITOR OPTIMISATION (THDV %)



B Select Harvest case study

We received complaints regarding harmonic issues from customers in the Northern Murray region. One of these customers is Select Harvest who experienced power quality problems at their Lake Cullulleraine site.

The details of the issue and its resolution are provided in this section.

B.1 Site information

The Select Harvest Lake Cullulleraine site is supplied from the MBN31 feeder, situated about 55km from the zone substation. This is an agricultural pumping station site, primarily using VSD drives to pump water from the lake to the farm. Additionally, several air conditioners are employed to maintain the temperature in the drives.

B.2 Issue investigation summary

The air conditioners, essential for cooling the drives, frequently tripped due to high harmonics. This resulted in the drives tripping and halting the pumping process. It was impacting the business's production and incurring additional labour costs to operate the pumps.

We investigated and discovered high harmonics in the area, with harmonics reaching up to 18 per cent. It was identified that Select Harvest sites, along with some nearby sites, were generating harmonic currents, consequently elevating the voltage harmonic level.

We collaborated with the customers to decrease harmonic current levels at non-compliant sites. Following the installation of harmonic filters at several sites, we logged harmonic data and observed a substantial improvement in the voltage harmonic levels as shown previously in figure 6 above. The total voltage harmonic distortion was 12 per cent, still exceeding the limit during peak pumping periods, which led to the tripping of air conditioners at the Select Harvest site.

Select Harvest engaged Azzo[5] for an independent review of power quality at their site. Azzo conducted harmonic data logging at the Select Harvest site after installing harmonic filters and prepared a power quality report. The report indicated that the harmonic levels at the site had improved and were brought under the compliance limit. However, the Azzo power quality report indicated that the harmonics at the Select Harvest sites reached up to 11.4 per cent during the logging period, with background harmonics recorded up to 8.9 per cent, exceeding the allowable limit. As a result, Azzo suggested implementing a harmonic filtering solution at the upstream network.

B.3 Resolutions

We implemented several strategies to mitigate the harmonic issues experienced at Select Harvest's sites and other nearby locations

1. We conducted data logging and identified non-compliant sites. Subsequently, we collaborated with the customers to reduce harmonic levels. While this step helped improve the harmonic levels, the issue has not been fully resolved.

[5] Case Study: Select Harvests — AZZO - Bringing technology together to enable global energy transformation, https://www.azzo.com/news/select-harvests

2. We provided additional generation support to the customer during the summers of 2022/23 and 2023/24 to operate air conditioners from a clean power source, thereby avoiding tripping the air conditioners
3. We tested and provided an UPS unit to the customer during the summer of 2023/24 to supply power to the air conditioner units.

However, the resolutions 2 and 3 are considered a temporary solution and is suitable only for small systems.

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