Business Case
Power Quality

ERGON ENERGY
NETWORK

Executive Summary

Ergon Energy has over 98,000 distribution transformers with fewer than 3% currently having a PQ monitor. As most of rural and SWER distribution transformers supply single or very few customers, Ergon Energy has extremely limited capability to observe and analyse power quality issues of almost entire LV networks and connected customer population.

Increasing uptake of sensitive electronic equipment, various forms of disturbing loads, and embedded generation systems such as Solar Photovoltaics (PV) by customers within the Ergon Energy network is having significant impacts on network Power Quality (PQ) parameters and customer quality of supply within medium voltage (MV) and especially low voltage (LV) networks. Ergon Energy aspires to continue to deliver and improve upon existing Power Quality performance despite rapidly changing patterns of behaviour, meeting customer expectations associated with a modern electricity grid and enabling customers to reap the benefits of distributed generation.

This business case seeks an extension of the existing regulatory control period 2015-20 program of works, which broadly includes PQ monitoring and analytics capability. The proposal also introduces a new program of augmentation works to allow bidirectional power flow and rectify power quality issues caused by the rapid uptake of Solar PV, thereby improving customer Quality of Supply (QoS), network affordability for future penetration of PV systems, and ensuring network compliance and safety. The AER, in the draft distribution determination, have already recognised and accepted that Ergon Energy's expenditure proposal with regards to reactive management of existing and future PQ issues caused by solar PV is prudent and efficient.

Three options were evaluated as part of this business case:

Option 1 – A counterfactual, 'do nothing' option under which no works are performed to improve Power Quality monitoring.

Option 2 – Solar PV augmentation works will be performed during the 2020-25 regulatory period in order to maintain compliance with relevant safety and performance standards.

Option 3 – Extension and upgrade of the existing PQ Monitoring capability in the Ergon Energy network, by connecting PQ monitors to a further 1.5% of distribution feeders. Also includes the augmentation works proposed under Option 2.

Ergon Energy aims to minimise expenditure in order to keep pressure off customer prices, however understands that this must be balanced against critical network performance objectives. These include network risk mitigation (e.g. safety, bushfire), regulatory obligations (e.g. safety), customer reliability and security and preparing the network for the ongoing adoption of new technology by customers (e.g. solar PV). In this business case both reliability and supporting the adoption of new technology by customers are strong drivers, based on the need to improve Power Quality monitoring and analytics capabilities to assist Ergon Energy with managing the ongoing uptake of solar PV systems by customers.

To this end, Option 3 is the preferred option. It provides the most cost-effective means of addressing the need for solar PV augmentation works and increased Power Quality monitoring, with a Net Present Value (NPV) result of -$14.0M. It is important to note that when considered separately, the expansion of Power Quality monitoring under Option 3 is NPV positive, delivering an NPV result of $8.7M.

The direct cost of the program for each submission made to the AER is summarised in the table below. Note that all figures are expressed in 2018/19 dollars and apply only to costs incurred within the 2020-25 regulatory period for the preferred option.

Regulatory Proposal	Draft Determination Allowance	Revised Regulatory Proposal
$15.6M	$0	$15.6M

The preferred option also supports the recommendations from the Australian Energy Market Commission (AEMC) to the DNSPs to continue improving modelling and visibility of their LV networks in the authority’s review paper titled “Integrating DERs for the Grid of the Future”, published in September 2019.

The program presents customer benefits by enhancing quality of service through improved network visibility and the move to a more reactive response model. Issues associated with solar PV curtailment, potential equipment damage, and PQ issues such as noise are expected to be reduced through the program, despite rapidly changing patterns of behaviour. The modestly extended PQ monitoring capability (with only 1,440 additional PQ monitors) is expected to reduce the cost of QoS enquiries, processing of connection applications, and investment into network augmentation works, by reducing the need for manual data collection and improving Ergon Energy’s understanding of the causes and effects of PQ problems.

Finally, this program assists Ergon Energy in a transition to the intelligent grid of the future. Beyond 2020, together with other initiatives, the PQ monitoring program will enable application of intelligent grid solutions (including planning and management of micro-grids), development of technology platforms for monitoring and analysing of distributed and disturbing energy resources, and support supply power quality on MV and LV networks in the future.

Contents

1 Introduction

Ergon Energy's Power Quality (PQ) strategic proposal for the regulatory control period 2020/21-2024/25 is targeted at monitoring and managing both network and customer issues regarding power quality. This expenditure proposal seeks an extension of the existing regulatory control period 2015-20 program of works, which broadly includes PQ monitoring and analytics works, identification and rectification of PQ issues, and management of the low voltage (LV) and medium voltage (MV) networks. It also covers expenditure relating to works required to allow bidirectional power flow and rectify power quality issues due to emerging Solar Photovoltaic (PV) constraints in LV networks.

1.1 Purpose of document

This document recommends the optimal capital investment necessary for the Ergon Energy Power Quality Program. This is a preliminary business case document and has been developed for the purposes of seeking funding for the required investment in coordination with the Ergon Energy Revised Regulatory Proposal to the Australian Energy Regulator (AER) for the 2020-25 regulatory control period. Prior to investment, further detail will be assessed in accordance with the established Energy Queensland investment governance processes. The costs presented are in $2018/19 direct dollars.

1.2 Scope of document

The scope of this proposal is for Power Quality programs which are targeted at low voltage (LV) and medium voltage (MV). The programs are primarily based on the current regulatory requirement to maintain statutory voltages within the range 230 V +10/-6% and will mainly address the worst areas emerging from the growth of emerging technologies (Electric Vehicles (EV), Solar PV, storage batteries, and sensitive appliances) connected on the network.

This program also focuses on identifying non-compliant areas of the network with respect to statutory voltages and other network PQ parameter standards, to develop and implement a targeted program of prioritised remediation works that will reduce non-compliance over the next regulatory period.

This strategic proposal covers expenditure for programs in two categories:

1 Power Quality Monitoring; and,
2 Solar PV related augmentation works.

1.3 Identified Need

Ergon Energy aims to minimise expenditure in order to keep pressure off customer prices, however understands that this must be balanced against critical network performance objectives. These include network risk mitigation (e.g. safety, bushfire), regulatory obligations (e.g. safety), customer reliability and security and preparing the network for the ongoing adoption of new technology by customers (e.g. solar PV). In this business case both reliability and supporting the adoption of new technology by customers are strong drivers, based on the need to improve Power Quality monitoring and analytics capabilities to assist Ergon Energy with managing the ongoing uptake of solar PV systems by customers.

Power Quality issues are becoming more prominent in the Ergon Energy network as uptake of sensitive electronic equipment, various forms of disturbing loads, and embedded generation systems accelerates. In response to customer engagement, Energy Queensland (EQL) has developed two complementary strategies to manage typical network Power Quality parameters such as overvoltage, under-voltage, sags, swells, flickers, imbalance and harmonics. These strategies, the Customer Quality of Supply Strategy and the Low Voltage Monitoring Strategy (henceforth referred to as the Power Quality Strategies), set out the requirements to deliver an improved network monitoring system, capable of:

- Reporting on the state of the network for all the Power Quality parameters;
- Assisting in remediation works necessary to improve Power Quality outcomes; and,
- Assisting in the decision making for network augmentation work and connection of new customers to meet Power Quality standards and targets.

These strategies also address the network PQ obligations, drivers and future requirements, with a major focus on voltage management on all parts of the network. Power Quality performance monitoring and improvement works are also envisaged to drive prudent and efficient investments on network augmentation.

As part of previous Power Quality programs of work, around 3,000 PQ monitors have been installed across the Ergon Energy network, providing coverage of less than 3% of distribution transformers in the network. Additionally, there are currently 150 power quality analysers in Ergon Energy network. These assets have already delivered noticeable benefits to Ergon Energy; however, many more additional PQ monitoring devices are required to ensure compliance and increase central visibility the network.

The need to extend the PQ monitoring program aligns with internal Energy Queensland strategies including the Power Quality Strategies, the Future Grid Roadmap, and the Intelligent Grid Technology Plan, as well as external strategies and aims for Queensland electricity networks:

- **Customer engagement programs:** EQL customer engagement programs indicate that customers are in favour of investments which make the grid 'smarter' and allow for use of more modern technologies. Customers with Distributed Energy Resources (DERs) want to gain the greatest economic benefit out of their assets without disruption to normal supply. The program will allow EQL to better understand the impact of DERs and changing patterns of customer activity on QoS, and plan works and regulations accordingly to maximise the benefit of these assets.
- **Leading industry knowledge:** The AEMC recently published a review paper titled "Integrating DERs for the Grid of the Future", which highlights the need for Distribution Network Service Providers (DNSPs) to continue to develop business cases for improvement of modelling and monitoring of their LV networks, particularly in response to challenges caused by the rapid uptake of Solar PV. This program responds to this need by expanding Ergon Energy's LV and MV monitoring capacity, and acknowledges EQL's involvement in research programs for alternative monitoring solutions such as use of smart-meters as well of the current limitations of these solutions.
- **Government policy:** The Powering Queensland Plan developed by the Department of Natural Resources, Mines and Energy sets out a target of 50% renewable energy supply by 2030. This program will help EQL optimise the uptake and operation of DERs into LV and MV networks, ensuring that uptake is not hampered by voltage or QoS issues and that where possible, network augmentation and investment can be limited by smart application of DERs.

This program is expected to deliver the following customer outcomes:

- **Ensuring Customer Benefits and Intelligent Grid Outcomes:** The main rationale of the PQ program is to allow, where possible, all customers benefit from being able to draw load or generate into the network through Distributed Energy Resources (DERs) such as Solar PV or batteries, while also ensuring that the network conforms to all power quality parameters and relevant standards.

- **Driving Prudent Investment:** Power Quality data from a network of PQ monitors can be used to target prudent network augmentation. Where there are no PQ monitors, augmentation projects rely on network modelling data and some short-term recordings in limited locations to identify issues and potential solutions. Actual metered PQ data will allow for validation of network modelling outcomes and increased confidence in augmentation investment decision making, and over time will lead to improved accuracy of network models. With even the limited existing PQ monitoring capability in the Ergon Energy network, PQ data has been able to demonstrate that augmentation works are unnecessary, leading to cost savings across the business. The additional PQ data will ensure that investments are applied to address confirmed existing and emerging capacity constraints.
- **Improving Safety Outcomes:** Ergon Energy needs to be able to proactively identify, investigate and rectify any PQ related customer, network or non-compliance issues. With increased monitoring of PQ parameters, the likelihood of damage to customer or network equipment from exposure to very high or otherwise unregulated voltage will be reduced, and the safety outcomes will improve for staff and customers who could otherwise be exposed to unregulated voltages.

This proposal aligns with the CAPEX objectives and criteria from the National Electricity Rules as detailed in Appendix C.

1.4 Energy Queensland Strategic Alignment

Table 1 details how the PQ program contributes to Energy Queensland's corporate and asset management objectives. The linkages between these Asset Management Objectives and EQL's Corporate Objectives are shown in Appendix D.

Table 1: Asset Function and Strategic Alignment

Objectives	Relationship of Initiative to Objectives
Ensure network safety for staff contractors and the community	Effective monitoring of the networks and a proactive response model will allow Ergon Energy to investigate and address issues before safety is impacted, equipment damage occurs, or customers become aware of the issue.
Meet customer and stakeholder expectations	Effective monitoring will reduce the number of Quality of Service enquiries and call-outs, and ensure the network is operating within all PQ standards. Additionally, this program responds to customer engagement programs which indicate customer enthusiasm for programs which help to deliver modern grid solutions. Improved LV network monitoring capability together with other initiatives, will enable application of intelligent grid solutions (including planning and management of micro-grids), and development of technology platforms for monitoring and analysing of DERs.
Manage risk, performance standards and asset investments to deliver balanced commercial outcomes	This program builds on benefits realised from previous PQ works, extending network functionality to increase Ergon Energy's ability to monitor and report on all parts of the network. Increased access to real-time data on PQ parameters also helps to inform efficient investment into remediation or augmentation works necessary to improve PQ outcomes, and allows Ergon Energy to take a balanced approach to investment and asset management.

Objectives	Relationship of Initiative to Objectives
Develop Asset Management capability & align practices to the global standard (ISO55000)	This approach is consistent with ISO55000 objectives and drives asset management capability by promoting a continuous improvement environment. Confidence in the information is improved to enable better reporting on the state of the network PQ parameters in documents such as the Distribution Annual Planning Reports (DAPR).
Modernise the network and facilitate access to innovative energy technologies	This approach promotes the use of developing technologies to improve customer outcomes, drive efficient investment, and allow increasing uptake of innovative energy technologies by customers across the Ergon Energy network in a manner that does not impact compliance or performance. Beyond 2020, together with other initiatives, the PQ Monitoring Program will enable application of intelligent grid solutions (including planning and management of micro-grids), development of technology platforms for monitoring and analysis of distributed energy resources and support future PQ initiatives on LV networks.

1.5 Applicable service levels

Corporate performance outcomes for this asset are rolled up into Asset Safety & Performance group objectives, principally the following Key Result Areas (KRA):

- Customer Index, relating to Customer satisfaction with respect to delivery of expected services
- Optimise investments to deliver affordable & sustainable asset solutions for our customers and communities

Corporate Policies relating to establishing the desired level of service are detailed in Appendix D.

Under the Distribution Authorities, EQL is expected to operate with an ‘economic’ customer value-based approach to reliability, with “Safety Net measures” for extreme circumstances. Safety Net measures are intended to mitigate against the risk of low probability vs high consequence network outages. Safety Net targets are described in terms of the number of times a benchmark volume of energy is undelivered for more than a specific time period. EQL is expected to employ all reasonable measures to ensure it does not exceed minimum service standards (MSS) for reliability, assessed by feeder types as

- System Average Interruption Duration Index (SAIDI), and;
- System Average Interruption Frequency Index (SAIFI).

Both Safety Net and MSS performance information are publicly reported annually in the Distribution Annual Planning Reports (DAPR). MSS performance is monitored and reported within EQL daily.

1.6 Compliance obligations

Table 2 below outlines the relevant compliance obligations for this proposal.

Table 2: Compliance Obligations Relevant to This Proposal

Legislation, Regulation, Code or Licence Condition	Obligations	Relevance to this investment
QLD Electrical Safety Act 2002 **QLD Electrical Safety Regulation 2013**	We have a duty of care, ensuring so far as is reasonably practicable, the health and safety of our staff and other parties as follows: • Pursuant to the Electrical Safety Act 2002, as a person in control of a business or undertaking (PCBU), EQL has an obligation to ensure that its works are electrically safe and are operated in a way that is electrically safe.1 This duty also extends to ensuring the electrical safety of all persons and property likely to be affected by the electrical work.[2]	This proposal addresses PQ issues in Ergon Energy LV and MV networks which can cause safety risks to customers, staff, and plant equipment through planned network augmentation and remediation works, and extends the PQ monitoring ability of the network, which will allow Ergon Energy to respond proactively to issues before they cause safety risks.
Distribution Authority for Ergon Energy issued under section 195 of *Electricity Act 1994* (Queensland)	Under its Distribution Authority: • The distribution entity must plan and develop its supply network in accordance with good electricity industry practice, having regard to the value that end users of electricity place on the quality and reliability of electricity services. • The distribution entity will ensure, to the extent reasonably practicable, that it achieves its safety net targets as specified. • The distribution entity must use all reasonable endeavours to ensure that it does not exceed in a financial year the Minimum Service Standards (MSS)	This proposal introduces measures to improve Quality of Supply for customers, reducing the impact of PQ factors such as harmonics, disturbances or voltage fluctuations which can impact service quality.
National Electricity Rules, Chapter 5	Schedule S5.1 of the National Electricity Rules, Chapter 5 provides a range of obligations on Network Services Providers relating to Network Performance Requirements. These include: • Section S5.1.9 Protection systems and fault clearance times • Section S5.1a.8 Fault Clearance Times • Section S5.1.2 Credible Contingency Events	This proposal introduces measures to control PQ issues covered by S5.1 including Magnitude of Power Frequency Voltage, Voltage Fluctuations, Voltage Harmonic Distortion, and Voltage Unbalance. By doing so this proposal improves Ergon Energy's ability to comply with the NER.
Queensland Electricity Act	Section 44A (1) of the Queensland Electricity Act states that it is a condition of a distribution authority that the distribution entity allow, as far as technically and economically practicable, a qualifying customer premise to connect one qualifying generator at the premises to its supply network.	This proposal will improve Ergon Energy's understanding of the impacts of DERs on the network and respond to voltage issues which currently limit the capacity of DERs which can be connected in LV networks, thereby allowing for optimisation of DER use and installation by Ergon Energy, and addressing factors which may currently limit the ability of residential customers to connect DERs.

[1] Section 29, *Electrical Safety Act 2002*
[2] Section 30 *Electrical Safety Act 2002*

1.7 Limitation of existing assets

Ergon Energy has over 98,000 distribution transformers with fewer than 3% fitted with PQ monitors. These PQ monitors have delivered successful quality of supply outcomes for both the network and customers. However, further works and extension of this monitoring program are required to ensure compliance and deliver additional benefits for Ergon Energy.

This section outlines:

- The benefits delivered from historical PQ Monitoring programs;
- The uptake of Solar PV in distribution networks; and,
- Additional limitations of the existing network which drive the need for extended PQ monitoring programs and traditional augmentation works.

1.7.1 Benefits of Historical Programs

Compliance with 230V AS61000.3.100 Standards

PQ monitors are connected to the LV terminals of less than 3% of the total population of distribution transformers across the Ergon Energy network. The installed PQ monitors provide a real-time response on the state of the network in areas where no other measurements are available and are the primary source to report on compliance for 230V standard and all PQ parameters throughout the Ergon Energy network. Figure 1 includes the data from revenue meters and manually read meters, along with ~2,800 remotely accessible Power Quality (PQ) monitors.

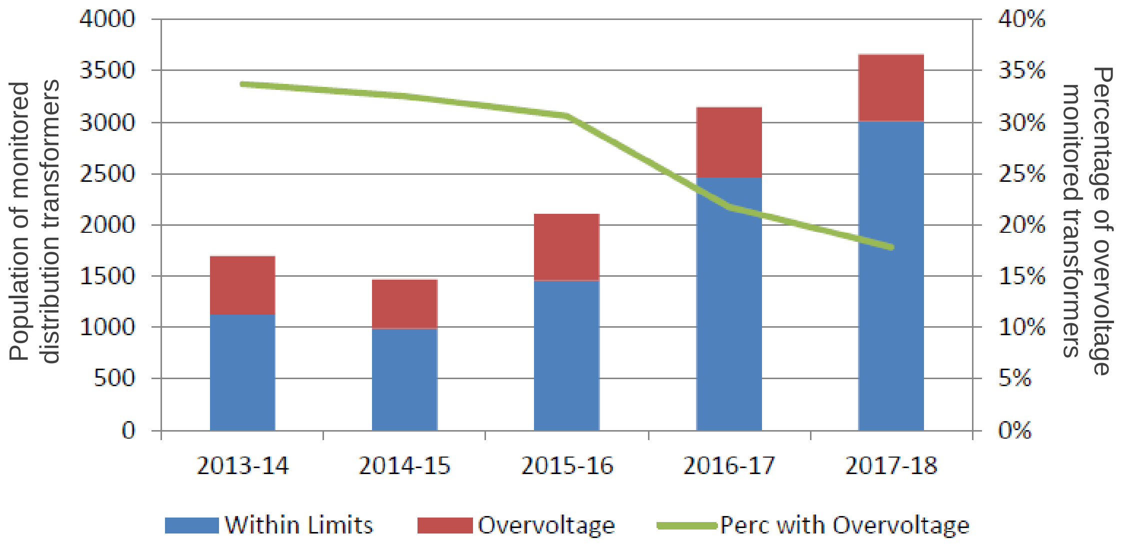

Figure 1: Population of monitored distribution transformers with over-voltage (V99%>253V)

Although Ergon Energy has largely achieved compliance in the transition to the 230V standard, there needs to be a greater number of transformers monitored to ensure the LV network is fully compliant with the standards for all other PQ parameters. The risk of non-compliance is with the sites where there are no monitors and no information on transformer tap positions. Additional PQ monitors will provide greater coverage and limit assumptions and risk about non-monitored parts of the network.

Savings in Field Investigations

Remote access to PQ monitoring data, availability of historical monitoring data, and improved visibility of the distribution network have made Quality of Supply (QoS) investigations and decision-making more efficient, with PQ data from often saving travel time and site visit costs for the field crews. Efficiencies are found through avoided set up and recovery of ad-hoc monitoring equipment at the distribution transformer and/or customer premise, reduced need for specialised ad-hoc PQ monitoring equipment and software, and reduced risk for staff conducting the field investigation.

PQ monitoring has resulted an approximately 30% reduction in overall investigation time and cost for voltage enquiries with field crews having remote access to PQ data before attending the sites (if site attendance is deemed necessary at all after remote analysis of data). However, provision for portable PQ monitoring devices is still often required at the connection point following a customer enquiry extending the investigation process due to very low penetration of PQ monitors, particularly on long rural feeders with very low customer densities. Further expansion of the PQ monitoring program is required before Ergon Energy can see widespread OPEX savings.

Benefits from Use of PQ Analysers

Power quality analysers are primarily installed on the High Voltage (HV) feeders supplying major customers such as resource sites like coal mines, minerals processing facilities, and industrial areas like sugar mills, ports and railways. There are also analysers monitoring major generation sites. The analysers provide real data on the power quality impact to the supply network.

PQ analysers mainly assist Ergon Energy by ensuring that customer connections remain compliant with their connection agreement and the relevant standards for various PQ parameters. They provide time and cost savings for connection enquiries and compliance investigations by avoiding the need for temporary equipment installation, recovery, and data analysis. Ad-hoc measurements generally do not provide the same quantity or quality of data required to carry out the same analysis, as observation periods are limited and statistically weak, particularly given the daily and seasonal variation of loads and generations and the variations in network topology.

Other advantages of PQ Analysers include:

- The ability to provide data after an event to determine the location or source of PQ issue.
- The ability to provide historic background readings for new customers to determine harmonics, inter-harmonics, and flicker allocations.
- Superior accuracy based on the highest standards set by the industry.

Additional Benefits

Additional benefits of the PQ monitoring program have included:

- Reductions in distribution transformer load checks on site.
- LV switching and load transfers are much quicker with minimal need to request load checks.
- Lesser generator use under contingencies as decisions can be based on historical load profiles.
- The Network Operation team can manage transfers with less capacity margin as they can observe loads in real time and make adjustments if necessary.
- Planning of LV ties and transfers are more accurate and faster with less reliance on simplistic load allocation models.
- Identification of any deviation of PQ parameters from acceptable performance levels through regular business reporting from the monitors. This includes prompt identification (and rectification) of sites with sustained high voltages with potential safety risk to the public/customers.
- Identification of faulty or failed line regulators or zone substation tap changes.

Due to multiple variables such as geographical locations of individual PQ monitors, customer numbers, distance from depot, crew availability, nature of Quality of Supply (QoS) enquiries, network topologies, and depth of required investigation it is very challenging to accurately model the operational cost benefits of individual PQ monitors. EQL will be exploring this aspect further as part of PQ mapping program.

1.7.2 Increasing Uptake of Small-Scale Solar PV

The following sections outline the trends observed in the Ergon Energy network regarding the uptake of Solar PV. For more information, refer to the supplementary information provided in Appendix H.

Historical and Projected Growth of DERs

Figure 2 shows the increase in Solar PV connections on LV networks since January 2012. As at the end of June 2018, almost 145,000 solar PV embedded generating systems of capacity between <1 kW and 50 MW, were connected to the Ergon Energy network, with a total installed capacity of approximately 770MW. The volume of PV connections over the past 12 months is almost 50% higher than in the previous 12 months, with the total PV capacity added being 300% higher, also due to the connection of several large solar farms. As at 30 June 2019, there were 160,166 solar PV systems connected with total inverter capacity of 1,240MVA. There are currently more than 500MW of applications awaiting approval for possible connection.

At the LV level, Ergon Energy networks have recorded sustained growth in connection of customers installing Solar PV systems. The growth rate has been approximately 30% per annum over the last five years, and the quantity of solar micro embedded generating units (< 30kVA) is currently increasing at an average of 1,400 systems per month. The current penetration rate of residential solar is 23%.

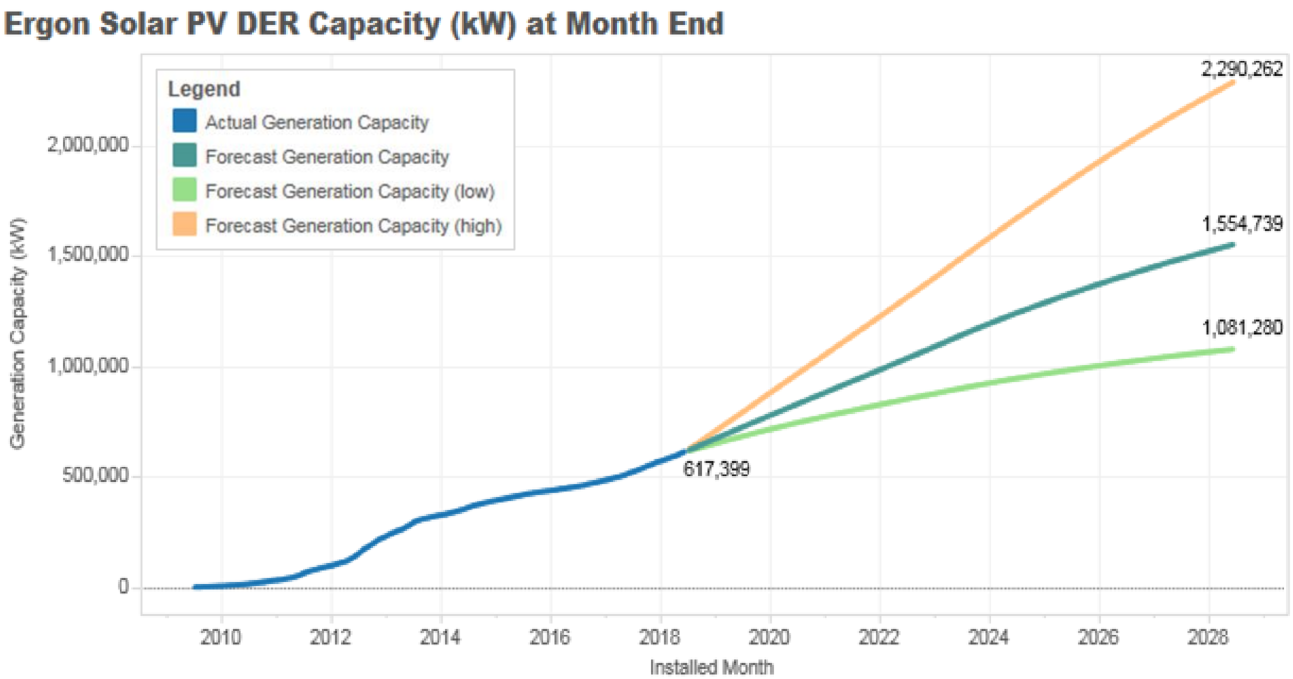

Figure 2: Real and Projected Solar PV Capacity Growth to 2030

Figure 2 also shows the projected growth of residential solar for Ergon Energy. It is very difficult to predict Solar PV uptake rates out as far as 2028 with any confidence given the range of influencing factors, including tariff incentives, capital cost, and customer behaviour in response to the rising price of electricity. The three scenarios modelled in Figure 2 assume that the cost of Solar PV systems has stabilised and the price of electricity from the grid is stabilised or reducing in real terms for customers. These two factors make it more likely that solar PV connections will decrease rather than increase. There is the possibility that further disruption through energy storage technologies such as standalone batteries or electric vehicle batteries integrated into existing solar PV systems could spur growth above the high scenario in the period to 2028, but at this stage, it is not considered likely.

The challenge for Ergon Energy is to incorporate the evolving behaviours and requirements of customers driven by the uptake of DERs into business as usual activities, allowing customers to take full advantage of intelligent grid technology benefits without impacting quality of service.

Network Impact – Reverse Power Flow and Voltage Impact

Solar PV and other forms of embedded generation have a large impact on network power quality due to the introduction of bi-directional power flow into low voltage networks. Traditionally, distribution networks were designed to accommodate the flow of power in one direction from substations through to customers, from HV to LV systems. With the rise in distributed generation on the LV network, power flows can now occur in both directions leading to greater voltage regulation challenges to be managed and operational issues to be addressed.

The large number of connections of rooftop Solar PV in some areas cause reverse power flows at times of peak solar generation. Figure 3 compares an example of a traditional and a high-solar penetration load profile on a distribution transformer, with reverse flow occurring during periods of peak generation. Approximately 32% of distribution transformers in the Ergon Energy network have Solar PV connected to them, and around 13% of the total population of the distribution transformers have PV penetration greater than 25% of their nameplate rating, which may result in reverse power flow back onto the HV during peak solar periods of the day.

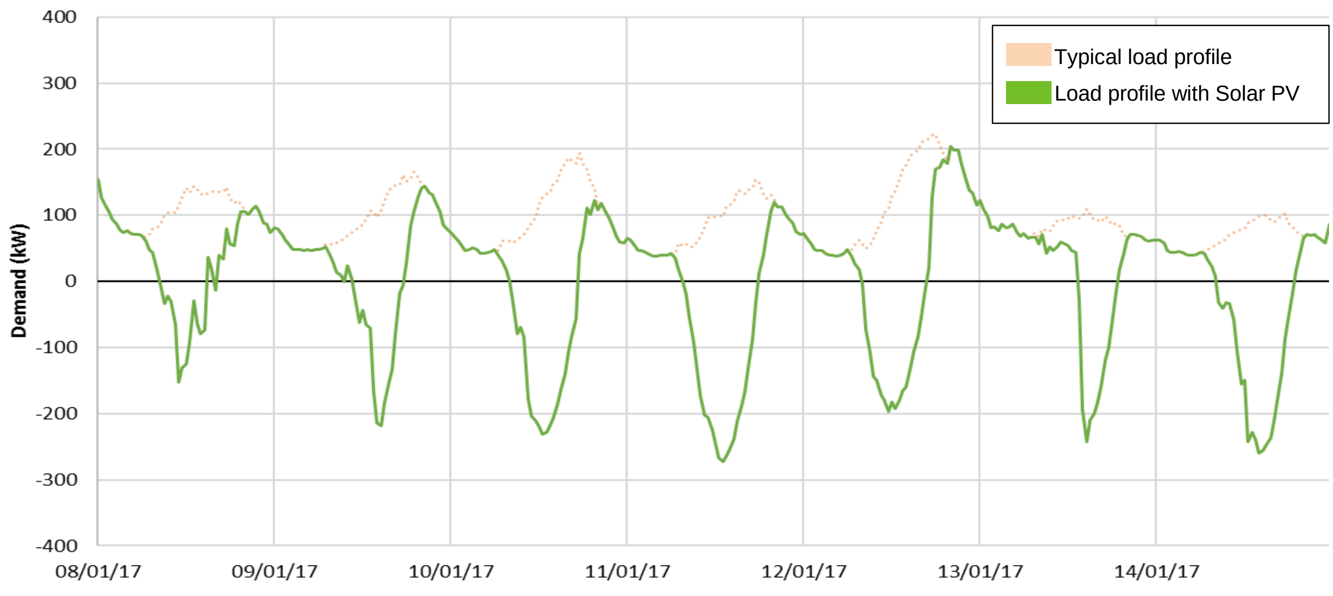

Figure 3: Example of traditional demand and solar load profile on a distribution transformer

Reverse power flow is less predictable and leads to both voltage rise and voltage drop along the feeding network, which must be managed to ensure voltage at customer terminals stays within statutory voltage limits. This additional voltage regulation required is very dependent on the actual network but is known to be worse in areas with overhead power line construction and longer LV circuit lengths connecting customers further away from supply substations. As solar PV penetrations continue to rise throughout Ergon Energy networks, reverse power flow and other associated PQ issues caused by solar PV will only become more prevalent.

Limited Visibility of DER Network Impact

The true difficulty in managing increased penetrations of DERs is the limited visibility of LV network power flows. While DNSPs may have visibility over most HV and MV networks through SCADA systems, there is limited direct monitoring of loads and voltages on LV networks, or data from direct monitoring of DER generation output or customer meters, as demonstrated by Figure 4.

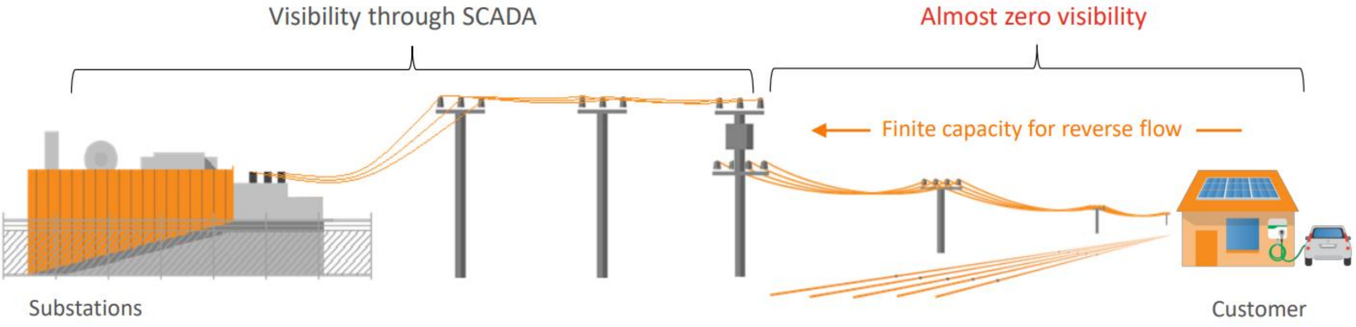

Figure 4: Limited or No LV Network Visibility for DNSPs (Source: AEMC, 2019)

Without increased monitoring of LV networks, issues such as reverse power flow are hard to identify in real-time and are often only noticed through customer complaints and enquiries. It is difficult to determine where constraints exist, and where they may develop in the future, limiting the ability of DNSPs to plan for increased DER integration.

The AEMC recently highlighted the need for increased LV network monitoring capability in a review paper titled “Integrating DERs for the Grid of the Future”, published in September 2019. The paper acknowledges the current constraints which DNSPs such as Ergon Energy experience, and outlines the need for additional monitoring and data collection in LV networks in order to support optimal use of DERs and network planning. For the Ergon Energy network, which currently has a high penetration of residential solar PV, and a very low coverage of PQ monitors on distribution transformers, expansion of LV monitoring capability will be incredibly important in planning and optimising the use and installation of DER assets.

Business Impact – Increasing QoS Enquiries

Although the network is achieving compliance with the new 230V standard on the part of the network with monitors, there are large sections of the network without monitors and therefore it is difficult to be certain that the network is compliant with a small number of monitors on a lower proportion of the transformers. The strategy used in the transition to 230V has seen a slight reduction in the number of QoS enquiries. Voltage and the other PQ issues continue to lead to Ergon Energy receiving Quality of Supply (QoS) complaints from customers. The percentage of QoS enquiries (complaints) across the Ergon Energy networks for Solar PV related issues has ranged from 40% to 56% over the last five years. Figure 5 shows the actual and projected number of QoS complaints due to Solar PV issues, based on the current and forecast proportions of customers with installed Solar PV.

In addition, network equipment failure (such as voltage regulator failure or tap change issues) can occur at any time resulting in voltages outside standard range, which will require real time detection and subsequent remediation. Increasing PQ monitoring capability in the network will improve Ergon Energy’s understanding of the causes and effects of different PQ issues, and allow for real-time detection or indication of PQ issues, thereby improving customer QoS.

EQL’s Customer Quality of Supply strategy for 2020-25 has a focus on monitoring distribution transformers that indicate a high percentage of customers with embedded generation. Increasing

Ergon Energy's understanding of the impact of DERs on LV and MV networks will have the following benefits:

- **Allowing increased uptake of DERs:** Additional PQ monitors on transformers with a high penetration of solar PV will provide a true indication of how the embedded generation is being used within (or impacting) the LV network, and if reverse flow is occurring into the MV network. If it can be demonstrated that embedded generation is used within the LV network (i.e. no reverse flow onto the MV), it may be possible to increase the percentage of embedded generation onto the transformers without causing reverse flow, or to reduce the amount of customer curtailment which is currently necessary to ensure compliance.
- **Improving safety outcomes:** Increased monitoring will help to ensure that load and generation currents within LV networks are balanced to ensure minimal neutral currents, improving safety outcomes. Existing PQ monitor data has been used to calculate neutral current parameters, and with further development around this calculation it is anticipated that further safety assumptions can be made.
- **Efficient investment for remediation or augmentation works:** More data on PQ parameters will help Ergon Energy to make more informed and efficient investment decisions about network augmentation or voltage remediation works, delivering improved customer outcomes in a cost-effective manner.
- **Reducing instance and cost of QoS enquiries:** With improved PQ monitoring capability, Ergon Energy can reduce the costs associated with QoS enquiries, and proactively plan network augmentation or voltage remediation works where necessary to reduce QoS issues for customers.

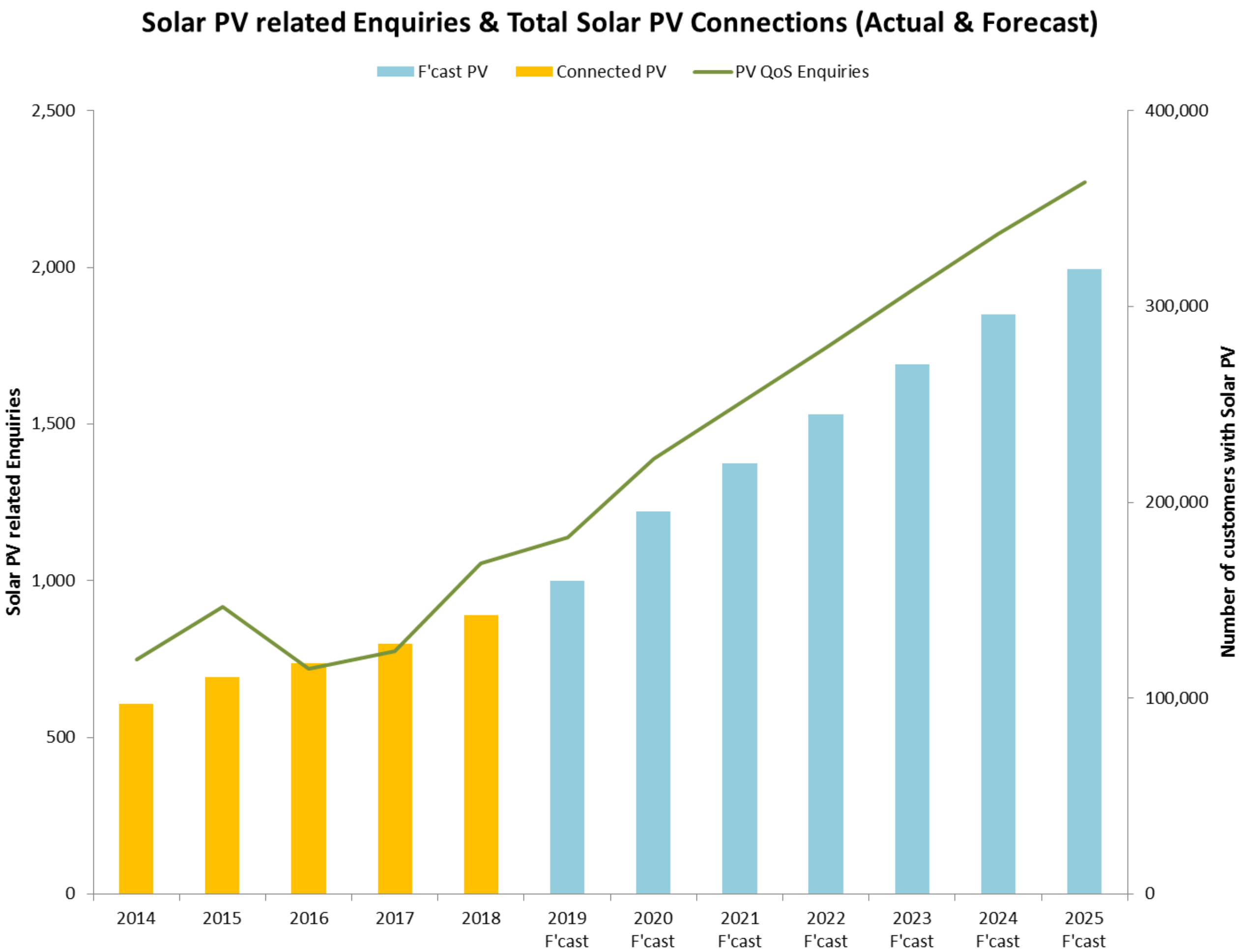

Figure 5: Number of Solar PV QoS enquiries and total Solar PV connection (Actual and Forecast)

1.7.3 Additional Limitations of the Existing Network and Programs

Improving Understanding of Network PQ Health, and Reducing Modelling Costs

Ergon Energy has over 98,000 distribution transformers with fewer than 3% currently fitted with PQ monitors. A large number of rural feeders have between one and four-line regulators installed to ensure greater voltage regulation capability. To monitor the operation of each section past a line regulator, there is a need for an increased number of PQ monitors. As per EQL's Customer Quality of Supply Strategy to target monitoring of distribution transformer with high penetration of Solar PV, Ergon Energy needs to be able to effectively monitor all parts and feeders of the network, including the distribution MV and Single Wire Earth Return (SWER) networks.

In the absence of suitably placed PQ monitors with communications capability, and subsequent lack of network performance history, Ergon Energy is reliant on confirmation of network health issues from multiple other sources. Field work for short-term monitoring and data collection is often necessary, using temporary PQ monitors, or sporadic PQ data readings from voltage regulators, or revenue meter data in the place of PQ monitor datasets. This method of validation results in significant work required from multiple groups at Ergon Energy, and significant additional labour and equipment costs. In addition, the benefit of short-term monitoring is limited because of the small window of data capture, and revenue meter data is not always useful as the quality of the data depends on the age and types of meters.

With the extension of PQ monitoring capability throughout the Ergon Energy network, the necessity of manual data extractions such as these would be reduced, with PQ monitors capturing real-time data during all periods of the year, improving data and model quality and reducing labour costs.

Improving Customer Experience through a Proactive Response Model

Ergon Energy's traditional response model is reactive, responding to issues following customer complaints, appliance damage, identified issues from network modelling, and post-event recording. With Ergon Energy's existing PQ monitoring capability, there have been numerous occasions where PQ monitors have identified low voltage wires down, blown fuses, unbalance and outages before the customers have made reports. There have been examples where PQ monitors have detected situations where livestock have contacted downed SWER wires, allowing the issue to be resolved prior to a member of the public or further livestock being endangered.

Expansion of the current PQ monitoring capability will allow Ergon Energy to move further from a reactive to proactive response model, and address existing and emerging network issues that adversely affect safety and QoS before safety is impacted, equipment damage occurs, or customers become aware of the issue. Improved data sets when performing QoS investigations will allow for better identification of the source of disturbances and their impact on customer supply. Through a proactive response model, a reduction in QoS related customer complaints and enquiries is expected, along with a reduction in customer claims for equipment damage.

Business Requirements – Transitioning to an Intelligent Grid

Energy Queensland's proposed PQ monitoring program also supports the transition to an intelligent grid, as proposed under the Future Grid Roadmap and Intelligent Grid Technology Plan. Visibility of all levels of the network is fundamental to the industry's transition from its current state to that of any future optimised DER world, and is required particularly to co-ordinate and optimise two-way energy flows on the network which arise from increased connection of DERs.

As part of this transition, EQL is proposing to implement systems such as an Advanced Distribution Management System (ADMS), a Distributed Energy Resources Management System (DERMS), and a Low Voltage Network Management Platform. These systems will allow coordination of customer DERs, which will increase utilisation of existing assets, reduce network augmentation, and enable better outcomes for customers in affordability and choice. At the same time, the increased visibility of the network from the proposed PQ monitoring program is a key requirement for the effective validation and implementation of these systems.

Beyond 2020, together with other initiatives, the PQ monitoring program will enable application of intelligent grid solutions (including planning and management of micro-grids), development of technology platforms for monitoring and analysing of distributed energy resources, and support future PQ initiatives on the Ergon Energy LV networks.

Business Requirements – Service Target Performance Incentive Scheme

The AER's Service Target Performance Incentive Scheme (STPIS) includes a performance index to report on the momentary supply interruption events (MAIFIe). MAIFIe measures the average frequency of momentary interruption events experienced by customers during a reporting period. A sustained interruption event is where one or more unsuccessful attempts to restore supply occur, and any associated momentary interruptions events are not included in the calculation of MAIFIe. The AER currently accepts that Ergon Energy does not have the capability to practically monitor and report MAIFIe but understands that the business is committed to establishing this capability in future. Delivery of the scope of work in this proposal will assist to achieve MAIFIe monitoring capability across the Ergon Energy high and medium voltage distribution networks and meet AER's potential future requirements for MAIFIe reporting.

2 Counterfactual Analysis

2.1 Purpose of asset

Ergon Energy has over 98,000 distribution transformers with fewer than 3% currently having a PQ monitor. As most of rural and SWER distribution transformers supply single or very few customers, Ergon Energy has extremely limited capability to observe and analyse power quality issues of almost entire LV networks and connected customer population. A large number of rural feeders have at least between one and four-line regulators installed to ensure greater voltage regulation. To monitor the operation of each section past a line regulator there is a need for an increased number of PQ monitors within a regulator section. Ergon Energy PQ monitors are connected to the low voltage (LV) terminals of the distribution transformer and provide a reflection of the medium voltage network including the PQ parameters. The installed PQ monitors have provided a real-time response on the state of the network in areas where no other measurements are available, and PQ Monitors are the primary source to report on compliance for the PQ parameters throughout the Ergon Energy network.

2.2 Business-as-usual service costs

In the 2010-2015 regulatory proposal, Ergon Energy was given approval for $5.0M for power quality monitoring. This funding was spent on PQ monitors and analysers to obtain a better understanding of the PQ parameters throughout the Ergon Energy network. These funds resulted in 1,300 monitors and 40 analysers being installed.

In the 2015-20 regulatory determination, additional funds of $4.8M were applied for and approved to provide 1,500 PQ monitors and 70 analysers along with the associated software to analyse and report on the PQ data. These are currently being rolled out under the program of works for power quality monitors. These investments have been shown to provide savings and benefits in augmentation work, customer claims and complaints, and help boost Ergon Energy's reputation in customer service. These include:

- Savings in time and costs associated with identifying possible need for network augmentation;
- Savings in time and reputation to identify customer enquiries on possible Quality of Supply and Power Quality issues;
- Savings in time, reputation, and payment costs for claims by customers for failed appliances and equipment;
- Savings in time and associated costs to install temporary recording equipment for network analysis to determine PQ parameters and compliance; and,
- Ability to ensure 230V compliance.

Ergon Energy's expenditure on PQ monitoring program for the regulatory control period 2015-20 is shown in Table 3.

Table 3: Ergon Energy PQ Monitoring program expense 2015-20

	2015/16	2016/17	2017/18	2018/19 Forecast	2019/20 Forecast
Expenditure (19/20 Direct $M)	$1.01	$0.68	$1.61	$1.37	$0.92

2.3 Key assumptions

The counterfactual analysis in this case is a ‘Do Nothing’ scenario, where no action is taken and there would be no additional expenditure for the monitoring program, or additional or augmentation works.

Under a ‘Do Nothing’ scenario, with the forecast increase in penetrations of Solar PV and other DERs such as household batteries and electric vehicles, it is highly likely that the network will likely see increased voltage rise and imbalance issues resulting in more customer complaints and unresolved PQ issues. Ergon Energy will be forced to respond reactively to these issues, having the following impacts on its operation:

- **Increased operating cost due to reactive emergency works:** Without planned solar PV augmentation programs to address known PQ issues, Ergon Energy will be forced to respond reactively to issues as they arise and are reported by customers, incurring additional cost due to the ad-hoc nature of works.
- **Higher safety risk associated with reactive works:** The risk to network staff and customers is higher under a reactive PQ response program, as PQ issues can expose persons to unregulated voltages, and cause damage to network or customer equipment.
- **Risk of non-compliance:** Without a planned program of works, Ergon Energy will be forced to respond reactively to issues, increasing the risk that non-compliant voltages will occur.

The counterfactual scenario also introduces the following issues for customers:

- **Increased risk of curtailment:** Without sufficient monitoring capability of LV networks, it is often difficult to diagnose the cause of PQ issues, and Ergon Energy may be forced to curtail customer DER exports in order to ensure compliance with voltage standards. Without a planned program of PQ monitoring or Solar PV augmentation, the likelihood of customer curtailment will increase.
- **Damage to customer equipment:** PQ issues in LV networks can cause damage to customer equipment, particularly sensitive electronic devices which have safety thresholds for voltage parameters. The counterfactual scenario will likely increase the risk of damage to customer equipment, and increase Ergon Energy’s exposure to customer damage claims.

Given the high likelihood of PQ issues arising during the next regulatory period that will need to be addressed through capital programs, the counterfactual program presents a poor asset management approach to network operation, and introduces unacceptable risks to customers, staff, and plant.

Additionally, the extremely limited availability of PQ data from the Ergon Energy network will impact its ability to manage, optimise, or derive benefit from the expected increase in DERs and other intelligent grid infrastructure. In order to drive cost-effective investment and support Ergon Energy’s transition to an intelligent grid in line with internal strategies, customer engagement, and government policies, Ergon Energy must introduce infrastructure that improves visibility of all levels of the network.

2.4 Risk assessment

This risk assessment is in accordance with the EQL Network Risk Framework and the Risk Tolerability table from the framework is shown in Appendix E.

Table 4: Counterfactual risk assessment

Risk Scenario	Risk Type	Consequence (C)	Likelihood (L)	Risk Score	Risk Year
Multiple customers' supply voltage is outside the regulated range (+10/- 6% of 230 V). These unregulated voltages lead to significant damage to customer equipment resulting in **significant impact on any restoration or planned works equating to business cost >$500,000**.	Business	4 *(Business cost >$500,000)*	3 *(Unlikely)*	**12** ***(Moderate Risk)***	2020
Inability to monitor and manage voltage in the regulated range (+10/- 6% of 230 V) and Audio Frequency Load Control (AFLC) signal levels, in particular in areas with high Solar PV penetration and long low voltage circuit lengths, potentially leads to breaching regulated standards and an **improvement notice being issued**.	Legislative	4 *(Improvement notice issued by regulator)*	3 *(Unlikely)*	**12** ***(Moderate Risk)***	2020
Inability to monitor and manage supply voltage outside of the regulated range (+10/- 6% of 230 V) and AFLC signal levels, in particular in areas with high Solar PV penetration and long low voltage circuit lengths, potentially results in an increase to customer light flicker and/or appliance/network equipment damage. This results in **disruption to businesses and essential services**.	Customer	3 *(Disruption to a large business or essential service)*	4 *(Likely)*	**12** ***(Moderate Risk)***	2020
Inability to monitor and manage voltage and AFLC signal levels, particularly in areas with high Solar PV penetration, potentially leads to poor network planning and business investment decisions. Energex is unable to deliver strategic initiatives related to optimal asset design with respect to new technologies without incurring costs resulting in **significant cost premium (>50% of estimates) to deliver agreed strategic initiatives**.	Business	3 *(Significant cost premium (>50% of estimates) to deliver agreed strategic initiatives)*	4 *(Likely)*	**12** ***(Moderate Risk)***	2020
Customer supply voltage is outside the regulated range (+10/- 6% of 230 V). Inadvertent contact with customer appliance or network equipment with very high voltages results in **a single fatality**.	Safety	5 *(Single Fatality)*	2 *(Very Unlikely)*	**10** ***(Low Risk)***	2020
Inability to monitor and manage supply voltage outside of the regulated range (+10/- 6% of 230 V) and AFLC signal levels, in areas with high Solar PV penetration and long low voltage circuit lengths results in **abnormal network**	Business	3 *(Abnormal network configuration)*	2 *(Very Unlikely)*	**6** ***(Low Risk)***	2020

Risk Scenario	Risk Type	Consequence (C)	Likelihood (L)	Risk Score	Risk Year
configuration while reactive work is undertaken to rectify issues.					

Further details of the risk ratings and descriptions can be found in Energy Queensland's Network Risk Framework.

2.5 Retirement or de-rating decision

Ensuring that supply Power Quality meets the required standards for voltage and other PQ parameters is crucial for the correct function of the Ergon Energy network and compliance with AER and NER standards and regulations. Without PQ monitoring devices, Ergon Energy would be unable to adequately monitor or predict PQ issues, resulting in poor customer quality of supply outcomes and inefficient investment into network augmentation or remediation works to address these problems. Existing network devices such as Automatic Circuit Reclosers (ACRs) and System Control and Ancillary Data Acquisition (SCADA) have no or very limited ability to provide remote visibility of PQ parameters. As such, retirement of PQ monitoring devices cannot be considered.

3 Options Analysis

Due to the complexity and the topology of the Ergon Energy network and the large number of distribution transformers involved, the management of power quality presents many challenges. To address these challenges a systematic approach is being adopted. This involves:

- Establishing objective measures and supporting systems for prioritising remedial works;
- Developing network models down to the LV network that allow problem areas to be predicted;
- Establishing suitable data acquisition and reporting systems to identify problem areas and implement remediation works;
- Tracking improvements from remediation programs; and,
- Measuring results to refine the network model and remediation options.

Options for programs of work to adopt the systematic approach outlined above have been developed for consideration in this business case.

3.1 Options considered but rejected

The following two options were considered but rejected when developing a program of works for extended PQ Monitoring:

- **Automatic Circuit Reclosers (ARCs) with SCADA for PQ Monitoring:** Use of ACRs was considered at a high level as a method for remote monitoring of Power Quality but rejected as these line devices have very limited ability to measure PQ parameters.
- **Customer Meter Data for PQ Monitoring:** Use of customer meter data is a potential future option for PQ monitoring, as it could provide access to PQ data from the entire Ergon Energy network in very high detail and frequency. EQL is currently involved in a research project as part of the of Australian Renewable Energy Agency (ARENA) funded Solar Enablement Initiatives Low Voltage State Estimation Algorithm (SEA) program, using smart meters and LV monitors to produce a real-time network model. However, a significant population of smart meters or LV monitors are required to provide accurate LV state estimation, with monitoring on a minimum of 25% of network nodes required for the SEA algorithm. Hence a development of SEA prototype has not been feasible for Ergon Energy due to low penetration of monitored sites.

3.2 Identified options

The identified options for this program of works are as follows:

- Option 1 – Do Nothing;
- Option 2 – PV Augmentation works only; and,
- Option 3 (Recommended) – Extend PQ monitoring capability and perform augmentation works (Full Program).

Option 1 – Do Nothing

The 'Do Nothing' counterfactual option was considered a viable option for analysis in this study, given the low historical volumes of expenditure for solar PV augmentation and the low coverage of PQ monitors in the network.

This option considers no planned capital expenditure but would likely occur some emergency expenditure due to the need to perform augmentation works in an ad-hoc manner when voltage compliance issues are identified.

Option 2 – PV Augmentation works only

Option 2 anticipates the need to perform solar PV augmentation works during the next regulatory period in order to maintain compliance with relevant safety and performance standards. This option does not consider any extension of PQ monitoring capability.

The number of sites requiring augmentation to rectify PQ issues due to Solar PV has been modelled based on the expected need for various forms of augmentation due to voltage constraints resulting from the increased PV penetration, predominantly recommending additional MV and LV line regulators.

The exact program of PQ associated network augmentation work will be determined as the network capacity becomes limited to increased demand from load and generation connection applications. Table 5 outlines the approximate program of works, based on the forecast need for MV and LV regulators.

Table 5: Solar PV augmentation program timing

PV Augmentation	2020/21	2021/22	2022/23	2023/24	2024/25	2020-2025 Total
MV line regulators	10	12	4	4	2	32
Low voltage regulators	60	60	100	115	115	450

The developed program of works acknowledges alternative options to managing PQ issues caused by increasing PV penetrations, such as enforcing AS/NZS4777 and curtailing customer PV exports.

Ergon Energy's approach is to manage connections in accordance with standards and observations provided by PQ monitoring. While QoS investigations do sometimes identify clearly non-compliant generator connections, enforcement of AS/NZS4777 has been problematic to implement due to the range of inverter models and the variability of network conditions (See Appendix H for further information on the application of this standard). Beyond disconnecting systems for a clear breach, Ergon Energy is not empowered to interrogate or adjust settings to identify breaches of connection agreements.

In order to provide customers with a choice, Ergon Energy has continued to allow PV systems up to 5kVA/phase to connect without export limits on non-SWER networks. Currently, PV systems larger than 30kVA are assessed on a case by case basis with partial or nil-export limits applied as required. With the rapid uptake of residential PV, system sized up to 200kVA might be allowed to automatically connect to the network which will further increase the need for visibility of the network with regards to PQ health.

In parallel, Ergon Energy is developing systems to support dynamic export limits to provide customers with greater opportunity to engage with the market with limits only imposed where and when network constraints could be breached.

Option 3 (Recommended)– Extend PQ monitoring capability and perform augmentation works (Full Program)

Option 3 represents the full program of work developed for this Power Quality Program. All augmentation work program presented in Option 2 is included in this option, alongside the extension and upgrade of the existing PQ Monitoring capability in the Ergon Energy network, by connecting PQ monitors to a further 1.5% of distribution feeders.

The volume of work for all the PQ monitoring programs is primarily based on level of PV penetration when compared to distribution transformer's nameplate rating. Since PV related QoS are predominant causes of customer complaints and higher PV penetration are likely to cause broader network issues, it is prudent to target and monitor networks with higher PV penetrations.

Due to the vast, diverse, and radial nature of the Ergon Energy network and the many types of distribution transformers, the aim of PQ monitoring program is to have PQ monitors installed to satisfy each the following criteria:

- At least one PQ Monitor all Single Wire Earth Return (SWER) feeders
- At least one PQ monitor on all 3 phase feeders
- One PQ monitor on all 3 phase feeder components. (A feeder component is a section past a line voltage regulator).
- One PQ monitor on 3 phase distribution transformers with a solar PV penetration greater than 75% of the transformer nameplate rating.
- The number of proposed PQ analysers has been determined by the number of feeders connected to industrial loads that are currently not monitored. Temporary recording equipment on some of these sites have indicated the need for further data and analysis to ensure compliance and impact on the network and other customers.

Based on the above criteria, analysis of network requirements for PQ monitoring in 2020-25 has identified the need for an additional 1,440 PQ monitors and 21 PQ analysers. These figures are based on the proportion of the current number of distribution transformers (~2,500) with Solar PV connection exceeding 75% of transformer kVA rating and the forecast increases in Solar PV connections. Table 6 outlines the planned program of works for extension of the PQ monitoring program.

Table 6: PQ Monitoring program timing

PQ Monitoring	2020/21	2021/22	2022/23	2023/24	2024/25	2020-2025 Total
PQ Monitors to be installed	270	300	300	300	270	1,440
PQ Analysers to be installed	3	5	5	5	3	21

This scope will ensure that investment in PQ monitoring equipment is extended further into the Ergon Energy network to ensure proficient monitoring of the network. Ergon Energy had explored different options regarding the volumes of PQ monitors that could be targeted for 2020-25. Higher numbers of monitors would definitely be beneficial in monitoring the PQ of the network. However, in response to customers concerns about price we decided to maintain the rollout of PQ monitors consistent with historical expenditure, rather than increasing as originally assessed. This approach was also in line with our overall approach to keep augmentation expenditure flat or reducing.

3.2.1 Non-Network Options

With the uptake of smart-meters and internet of things (IoT) solutions throughout the Ergon Energy network at customer residences, options for monitoring grid performance and use patterns by utilising existing smart assets are emerging.

EQL is currently involved in a research project as part of the of Australian Renewable Energy Agency (ARENA) funded Solar Enablement Initiatives Low Voltage State Estimation Algorithm (SEA) program, using smart meters and LV monitors to produce a real-time network model. However, a significant population of smart meters or LV monitors are required to provide accurate LV state estimation, with monitoring on a minimum of 25% of network nodes required for the SEA algorithm.

While the use of smart-meter data to model LV networks aligns with a recommendation presented by the AEMC in their recent paper "Integrating Distributed Energy Resources for the Grid of the Future", for DNSPs, in collaboration with industry and consumer representatives, to identify additional meter data that should be collected and made available in order to support LV network visibility, the low penetration of sites with smart-meters in Ergon Energy networks has prohibited the development of SEA prototype to date.

3.3 Economic analysis of identified options

3.3.1 Cost versus benefit assessment of each option

The Net Present Value (NPV) of each option has been determined by considering costs and benefits over the program lifetime from FY2020/21 to FY2039/40, using the EQL standard NPV analysis tool. The following costs and benefits have been considered for each option.

Capital Costs (CAPEX)

For each of the options assessed, a capital cost has been developed based on the planned and unplanned works which would likely be incurred during the next regulatory period. Table 7 outlines the key assumptions which were used to develop the CAPEX for each option.

Table 7: Options Capital Cost Assumptions Summary

	Capital Cost Category	
Option	**Solar PV Augmentation**	**PQ Monitoring**
Option 1 – Do Nothing	The full scope of works outlined in Table 5 is considered necessary to respond to customer complaints during the next regulatory period. Given that this is a new program of works for Ergon Energy, it is assumed that a 10% premium would be incurred due to the unplanned nature of works.	N/A
Option 2 – PV Augmentation & Remediation Only	Full scope of works as outlined in Table 5	N/A
Option 3 – Full Program (Recommended)	Full scope of works as outlined in Table 5	Full scope of works as outlined in Table 6

For the specific programs outlined in Table 5 and Table 6, capital costs were developed based on the unit rates outlined in Table 8. All unit rates are based on strategic estimates and are in line with typical expenditure in historical PQ programs. Unit rates also take into account both typical labour and materials costs, and the potential for geographical bundling of works.

Table 8: Unit Rate Assumptions for All Programs

Program	Description of CAPEX	Unit Rate ($/unit)
Power Quality Monitoring	Installation of PQ Monitors	$3,000
Power Quality Monitoring	Installation of PQ Analysers	$35,400

Program	Description of CAPEX	Unit Rate ($/unit)
Solar PV Augmentation	Install MV line regulators	$114,500
Solar PV Augmentation	Install LV regulators	$15,400

Operating Costs (OPEX)

Once installed, the OPEX costs for PQ monitors are negligible as there is no incremental inspection cost and minimal maintenance or replacement costs. As such, no OPEX costs have been included in this NPV analysis.

Ergon Energy however does attempt to address any voltage or PV related QoS queries via operational expenditures with network solutions such as LV load balancing, transformer tap changing etc. before exploring options that require capital expenditures. These OPEX costs are captured under separate categories. In addition, communication and ICT management costs are managed centrally, as part of operational technology programs.

Benefits (Avoided Expenditure)

Benefits associated with extended PQ monitoring capability through the Option 3 program have been modelled in this analysis as 'additional cost' in Options 1 and 2, therefore demonstrating that a comparative saving can be observed in Option 3.

Several expenditure categories have been identified based on the extension of PQ monitoring capability, and each is outlined in the following sections, with their total associated annual benefits summarised in Table 9.

For each avoided expenditure category, the annual value associated with installing additional PQ monitors is scaled in proportion to the number of monitors installed to date. For example, in Year 1 of the program, 273 PQ monitors out of a total 1,461 are installed under Option 2. Therefore ~19% of the total value shown in Table 9 is incurred in Year 1. By Year 5 when the program has been completed, 100% of the value is incurred annually, and in every year thereafter.

Table 9: Summary of Benefits (Avoided Expenditure)

Avoided Expenditure Category	Total Value ($/year)
Modelling for Small-Medium Connections	$17,165
Modelling for Large Connection Customers	$84,000
Installation of Portable / Short-Term PQ Data Recorders	$6,840
Savings on QoS Investigations	$130,200
Network Augmentation Savings	$250,000
Customer Compliance Claims Savings	$15,000
Voltage Regulator Setting Savings	$92,081
Distribution Transformer Tap Changer Savings	$355,622
Total	**$950,908**

Avoided Expenditure – Extra Network Modelling Time for Small-Medium Connections

Extra network modelling time is required to validate models for small-medium connections in the absence of PQ monitors:

- It has been estimated that with installation of PQ monitors on a further 1.5% of distribution feeders, that savings could be achieved in 1.5% of the approximately 596 Work Requests

(WR) received every year for new small-medium connections. This is likely a conservative assumption, as PQ monitor installation in this program will be targeted to areas with higher than average small-medium connections and DER activity.

- Consultation with network planning teams indicated that 16 hours of additional modelling time is typically required to conduct extensive model validation for connections with additional network complexities and without PQ data available, at a rate of $120/hour. Considering around 18 WRs annually, this results in savings of $17,165/year for Option 3.

Avoided Expenditure – Modelling for Large Connection Customers

Additional cost is incurred for network modelling and validation for large connection customers. Given the absence of PQ monitors on majority of the network, PQ monitor data from LV networks or manual data collection must typically be used to make assumptions on the PQ health of the network where the large connection applications are received.

- It was assumed that savings for network modelling for large customers on the MV network could be made in 20% of cases out of the typical 100 applications received per year, based on the placement of PQ monitors in Option 3.
- It was assumed that around 35 hours of additional resource for temporary network data collection (20 hours) and modelling (15 hours) could be saved with installation of PQ monitors. It should be noted that this time is slightly higher than that estimated for savings in the Energex Power Quality program (25 hours) as the Ergon Energy network is more diverse, requiring longer time periods to collate temporary data, and the penetration of large renewable energy generators which can create PQ issues is higher for regional Queensland, increasing modelling complexity. At a rate of $120/hour, considering 20 cases per year, this results in savings of $84,000/year for Option 3.

Avoided Expenditure – Installation of Portable / Short-Term PQ Data Recorders

In some cases, for connection application or enquiries to the Ergon Energy network, portable short-term PQ data recorders must be installed to collect data for network planning purposes or checking the PQ compliance, as there is no historical record of PQ data and no way to make accurate assumptions about the health of the network.

- Based on information from field investigations, it was conservatively assumed that around 20% of the average 18 uses of short-term recorders per year could be avoided with the installation of new PQ monitors. Using an average of 20 hours for travel time and installation of portable monitors, and a rate of $95/hour for field staff, this results in savings of $6,840/year for Option 3.

Avoided Expenditure – Savings on QoS Investigations

Having a PQ monitor in place introduces substantial savings to QoS investigations for Ergon Energy, due to factors such as reduced travel times and simplified diagnostic modelling requirements.

- The recommended average cost of one QoS job without a PQ monitor is $4,646 in urban areas and $5,800 for rural areas. As cost savings associated with PQ monitor use vary between feeders and QoS job requirements, it was assumed that a 30% saving could be achieved on QoS jobs for all feeder categories where a PQ monitor was in place. Using the lower value of $4,646 for an urban QoS job for conservatism, it was assumed that an approximate saving of $1,400 could be made for all feeder categories.

- The average annual number of QoS jobs is around 1,860. It was assumed that savings could be applied to 5% of these annual QoS jobs, or 93 jobs, based on the assumption that the PQ monitor installation program will be targeted to areas with higher than average QoS issues and DER activity. This results in savings of $130,200/year for Option 3.

Avoided Expenditure – Network Augmentation Saving

Network augmentation savings are realised in some cases where PQ monitors can be used to either reduce the cost of network augmentation needed to address voltage regulation issues, by delivering capital savings due to changes to project scope, or by deferring or cancelling projects entirely. It is difficult to estimate the exact impact of PQ monitors on network augmentation, due to the complexity and specifics of planning methods, the various potential sources of savings from PQ data use, and the various different approaches that can be taken to address voltage regulation issues.

- There is significant evidence of this benefit being realised with even the existing PQ monitoring capability. In the current regulatory period, seven network augmentation works projects have been cancelled due to data from PQ monitors confirming the PQ health status of the targeted network segments, resulting in total savings in the order of ~$700k. An additional example was of a single cancelled voltage regulator project worth $254,264 (work request no. DCP15673).
- In this analysis, given the examples provided, it has been conservatively assumed that savings of $250,000/year (approximately the total cost of two MV voltage regulators) could be achieved by Option 3 with improved monitoring capability. This equates to approximately 1.25% of total annual distribution Augex.

Avoided Expenditure – Customer Compliance Claims

The extension of PQ monitoring capability will provide Ergon Energy with a greater ability to monitor PQ non-compliance and address voltage issues which might cause damage to network and customer equipment, thereby reducing the volume of payment for customer claims due to equipment damage. Customers make a large number of claims annually for damaged equipment that they suspect failed due to network issues. These customer claims can be checked against PQ monitor data to see if the network was non-compliant at the time of the event leading to the claim. In several cases, data from PQ monitors have confirmed that the network was compliant, meaning that Ergon Energy is not required to pay out the claims, generating savings.

- An annual saving of $15,000 for Option 3 has been assumed, based on a 2% saving on estimated average annual payments by Ergon Energy to customers for damage claims related to network power quality issues.

Avoided Expenditure – Voltage Regulator Setting Savings

PQ monitors installed downstream of voltage regulators are used to verify network models for voltage regulator settings and also for detection of failed regulators and/or changes required in regulator settings. Use of PQ monitors therefore enables Ergon Energy to reduce the labour requirement associated with manually checking or adjusting voltage regulator settings across the network in response to QoS or other PQ issues.

- It was estimated that labour works could be avoided for 2% of the total population of 871 voltage regulators, and 1% of the total population of 288 zone substations under Option 3.
- This estimation is based on number of factors, including penetration levels of PV systems, feeder topologies, loading and voltage profiles, location of voltage regulators, and their controlled feeder sections' technical characteristics. In addition, there is an increasing trend of

Ergon Energy feeders and zone substations with reverse power flows affecting settings of existing line and zone substation voltage regulators. For example, based on the forecasting minimum demand data it is estimated that 155 distribution feeders (or 13% of total population of Ergon's distribution feeders) and verified 24 zone substations (8%) in Ergon network have reverse power flows.

- A labour saving of $4,536 has been applied in each case, based on a typical work time of around 38 hours at a rate of $120/hour. Taking into account the unit populations, this results in an additional cost of $92,081/year for Option 3.

Avoided Expenditure – Distribution transformer tap changer savings

Similarly, use of PQ monitors enables Ergon Energy to reduce the labour requirement associated with adjusting distribution transformer tap settings. PQ monitors installed on distribution transformers are used to verify network models for tap changers' positions and also for detection of overloading and inappropriate tap settings.

- The Ergon Energy network has extensive penetration of PV systems in LV networks controlled by distribution transformers with different tap settings (with 5 or 7 steps between buck, neutral and boost positions). On an annual basis, around 28% of customer QoS complaints are due to voltage regulation issues (besides the ones arising directly from solar PV penetration) against the distribution transformers where there are no PQ monitors (520). In order to rectify the voltage issues raised by one QoS complaint, more than one transformer may require tap changing.
- It is estimated that labour works could be avoided on approximately 15% of these transformers if the need for transformer tap changers were identified proactively by extended PQ monitoring capability. This equates to a cost saving on around 0.08% of the total population of 98,000 distribution transformers.
- Using the same labour saving of $4,536 as applied for voltage regulator setting savings, this results in an additional cost of $355,622 per year for Option 3.

Results

Based on each of the costs and benefits (modelled as additional costs incurred in Options 1 and 2) described in the previous sections, the Net Present Value (NPV) of each option was calculated. Table 10 outlines the results of NPV analysis for all options, displaying the CAPEX and Additional Costs incurred by each option over the study period, discounted at the Regulated Real Pre-Tax Weighted Average Cost of Capital (WACC) rate of 2.62%.

Option 3 has the least negative total NPV overall, making it the most cost-effective option. Despite the lower capital cost of Options 1 and 2 without the PQ monitoring program, the additional costs incurred without the program results in Option 3 being more cost-effective.

Table 10: Net Present Value of Options

Option	CAPEX PV ($M)			Additional Cost PV ($M)	NPV ($M)	Rank
	PQ Monitoring	PV Augmentation	Total			
Option 1 – Do Nothing	-	(10.39)	**(10.39)**	(13.19)	**(23.58)**	**3**
Option 2 – Augmentation Works Only	-	(9.45)	**(9.45)**	(13.19)	**(22.63)**	**2**
Option 3 – Full Program (Recommended)	(4.51)	(9.45)	**(13.96)**	-	**(13.96)**	**1**

Additionally, we can examine the PQ monitoring component of Option 3 alone to show that the program by itself is also NPV positive.

Considering the benefits associated with Option 3 as a positive 'savings' cashflow rather than a lower comparative cost as in Table 10, the results in Table 11 demonstrate that the PQ monitoring component of Option 3 alone has a positive NPV of $8.68M. The Benefit Cost Ratio (BCR) of this program component was calculated as 2.92, meaning that for each dollar spent in funding the Option 3 PQ monitoring CAPEX, almost three dollars are generated in cost savings across the Ergon Energy network.

Table 11: Net Present Value of Option 3 PQ Monitoring Component

Option	CAPEX ($M)	Savings ($M)	NPV ($M)	BCR
Option 3	(4.51)	13.19	8.68	2.92

3.4 Scenario Analysis

3.4.1 Sensitivities

Sensitivity analysis was considered on the following variables:

- **PQ Program CAPEX:** Sensitivities of +/- 20% were considered on the capital cost associated with extension of PQ monitoring capability.
- **Remediation & Augmentation Programs CAPEX:** Sensitivities of +/- 20% were considered on the capital cost associated with the customer voltage remediation and solar PV augmentation programs.
- **Avoided Expenditure:** Sensitivities of +/- 20% were considered on the total value of avoided expenditure associated with Option 3 compared to Options 1 and 2. Due to the number of expenditure categories considered, and the uncertainties associated with each, sensitivity was considered on the total value rather than on each individual category.

The results of sensitivity analysis are shown in Table 12. Under every sensitivity tested Option 3 had the most cost-effective (least cost) NPV.

Table 12: Results of Sensitivity Analysis

NPV ($M)	Base Scenario	Augmentation Program CAPEX		PQ Program CAPEX		Avoided Expenditure	
		-20%	+20%	-20%	+20%	-20%	+20%
Option 1 – Do Nothing	(23.58)	(21.50)	(25.66)	(23.58)	(23.58)	(20.94)	(26.21)
Option 2 – Augmentation Works Only	(22.63)	(20.74)	(24.52)	(22.63)	(22.63)	(20.00)	(25.27)
Option 3 – Full Program	(13.96)	(12.07)	(15.84)	(13.05)	(14.86)	(13.96)	(13.96)
Least Cost Option	*Option 3*	*Option 3*	*Option 3*	*Option 3*	*Option 3*	*Option 3*	*Option 3*

3.4.2 Value of Regret Analysis

In terms of selecting a decision pathway of 'least regret', Option 3 will allow for better management of PQ issues, more efficient and targeted investment into network capital programs to address identified issues, and the ability to predict and respond proactively to issues before they present safety or Quality of Supply issues.

While Option 3 presents the highest CAPEX of the considered options, the significant benefits provided by enhanced PQ monitoring mean it has the lowest NPV of the options considered and make it the least regret option. This program only seeks extension of existing capability in line with current expenditure and does not unnecessarily accelerate spending in line with concerns raised through customer engagement about network costs.

Without extension of PQ monitoring capability, Ergon Energy will lose access to another five years of data, particularly limiting its future ability to understand the operation of MV network power flows. Given the very low coverage of PQ monitors within the network to date, Ergon Energy is very limited in its ability to detect, predict, or plan for PQ issues, which will only become more common with the rapid uptake of DERs. Extension of PQ monitoring is essential for future network optimisation.

3.5 Qualitative comparison of identified options

3.5.1 Advantages and disadvantages of each option

Table 13 details the advantages and disadvantages of each option considered.

Table 13: Qualitative Assessment of Options – Power Quality Monitoring

Options	Advantages	Disadvantages
Option 1 – Do Nothing	• Lowest planned CAPEX program	• Additional cost incurred due to the emergency nature of works required to address voltage problems caused by Solar PV (not modelled) • Limited and reducing affordability for connection of new DERs until end of 2024/25 • Additional costs incurred to standard operations due to lack of PQ monitoring in the wider Ergon Energy network • PQ visibility until end of 2024/25 will be limited only to a minimum number of distribution transformers and LV feeders • Does not support Ergon Energy or EQL strategies for modernising the grid or encouraging DER uptake
Option 2 – Augmentation works only	• CAPEX savings from excluding monitoring programs • Planned nature of works to address solar PV issues represents good application of asset management principles	• Additional costs incurred to standard operations due to lack of PQ monitoring in the wider Ergon Energy network • PQ visibility until end of 2024/25 will be limited only to a minimum number of distribution transformers and LV feeders • Does not support Ergon Energy or EQL strategies for modernising the grid or encouraging DER uptake

Options	Advantages	Disadvantages
Option 3 (Recommended) – Extend PQ monitoring capability and perform augmentation works	• Better ability to manage and monitor PQ in the network, and thereby reduce QoS complaints and reduce costs associated with service callouts • Drive efficient network investment through greater ability to model and monitor network • Improved affordability for connection of new DERs until end of 2024/25 • Improved and extended PQ visibility to more distribution transformers and LV feeders • Strategic alignment with internal strategies, customer engagement, AEMC suggested actions, and Queensland Government policy	• Higher CAPEX associated due to installation of PQ monitors

In addition, based on historical installation trends and forecast connection applications, the penetration of Solar PV and other DERs in the Ergon Energy network is only going to increase over time. This is in line with the Queensland Government renewable energy target of 50% by 2030, as well as findings from wider customer engagement programs. At the same time, implementation of smart grid technologies is increasingly common across the network on both the customer and network side.

Implementation of the preferred Option 3 will see the extension of current PQ monitoring capability, giving Ergon Energy improved visibility of the network and an enhanced understanding of the impacts of increasing DER penetration. The AEMC's recent publication on "Integrating Distributed Energy Resources for the Grid of the Future" outlined the following two key recommendations directly related to increased LV network monitoring:

- DNSPs should continue to develop business cases for improvement of modelling and monitoring of their LV networks.
- DNSPs, in collaboration with industry and consumer representatives, should identify additional meter data that should be collected and made available in order to support LV network visibility, in a manner that maximises net benefits to consumers.

This program is aligned with these AEMC recommendations and prepares Ergon Energy for a future where smart grid technologies are ubiquitous. Implementation of Option 3 will allow for better management of PQ issues, more efficient and targeted investment into network capital programs to address identified issues, and the ability to predict and respond proactively to issues before they present safety or Quality of Supply issues.

3.5.2 Alignment with network development plan

The preferred option aligns with the Asset Management Objectives in the Distribution Annual Planning Report. In particular it manages risks, performance standards and asset investment to deliver balanced commercial outcomes while modernising the network to facilitate access to innovative technologies.

3.5.3 Alignment with future technology strategy

This program is aligned strongly with the Future Grid Roadmap and Intelligent Grid Technology Plan, as it will allow Ergon Energy to improve their understanding of two-way energy flows in LV networks, facilitating efficient investment decision-making to address compliance and safety issues, and enabling connection of DERs to the LV grid in a safe and effective manner. Beyond 2020, together with other initiatives, the PQ monitoring program will enable application of intelligent grid solutions including planning and management of micro-grids, and development of technology platforms for monitoring and analysing of distributed energy resources.

3.5.4 Risk Assessment Following Implementation of Proposed Option

Table 14 outlines the risk assessment for the Ergon Energy network following implementation of the proposed Option 2 program.

Table 14: Risk assessment showing risks mitigated following Implementation

Risk Scenario	Risk Type	Consequence (C)	Likelihood (L)	Risk Score	Risk Year
Multiple customers' supply voltage is outside the regulated range (+10/- 6% of 230 V). These unregulated voltages lead to significant damage to customer equipment resulting in **significant impact on any restoration or planned works equating to business cost >$500,000**.	Business	(Original) 4 *(Business cost >$500,000)* (Mitigated) 4 *(As above)*	 3 *(Unlikely)* 2 *(Very Unlikely)*	 **12** ***(Moderate Risk)*** **8** ***(Low Risk)***	2020
Inability to monitor and manage voltage in the regulated range (+10/- 6% of 230 V) and AFLC signal levels, in particular in areas with high Solar PV penetration and long low voltage circuit lengths, potentially leads to breaching regulated standards and an **improvement notice being issued**.	Legislative	(Original) 4 *(Improvement notice issued by regulator)* (Mitigated) 4 *(As above)*	 3 *(Unlikely)* 2 *(Very Unlikely)*	 **12** ***(Moderate Risk)*** **8** ***(Low Risk)***	2020
Inability to monitor and manage supply voltage outside of the regulated range (+10/- 6% of 230 V) and AFLC signal levels, in particular in areas with high Solar PV penetration and long low voltage circuit lengths, potentially results in an increase to customer light flicker and/or appliance/network equipment damage. This results in **disruption to businesses and essential services**.	Customer	(Original) 3 *(Disruption to a large business or essential service)* (Mitigated) 3 *(As Above)*	 4 *(Likely)* 3 *(Unlikely)*	 **12** ***(Moderate Risk)*** **9** ***(Low Risk)***	2020
Inability to monitor and manage voltage and AFLC signal levels, particularly in areas with high Solar PV penetration, potentially leads to poor network planning and business investment decisions. Energex is unable to	Customer	(Original) 3 *(Significant cost premium (>50% of estimates) to deliver agreed strategic initiatives)*	 4 *(Likely)*	 **12** ***(Moderate Risk)***	2020

Risk Scenario	Risk Type	Consequence (C)	Likelihood (L)	Risk Score	Risk Year
deliver strategic initiatives related to optimal asset design with respect to new technologies without incurring costs resulting in **significant cost premium (>50% of estimates) to deliver agreed strategic initiatives**.		(Mitigated) 3 *(As above)*	 3 *(Unlikely)*	 **9** ***(Low Risk)***	
Customer supply voltage is outside the regulated range (+10/-6% of 230 V). Inadvertent contact with customer appliance or network equipment with very high voltages results in **a single fatality**.	Safety	(Original) 5 *(Single Fatality)* (Mitigated) 4 *(Multiple serious injuries)*	 2 *(Very Unlikely)* 2 *(Very Unlikely)*	 **10** ***(Low Risk)*** **8** ***(Low Risk)***	2020
Inability to monitor and manage supply voltage outside of the regulated range (+10/- 6% of 230 V) and AFLC signal levels, in areas with high Solar PV penetration and long low voltage circuit lengths results in **abnormal network configuration while reactive work is undertaken** to rectify issues.	Business	(Original) 3 *(Abnormal network configuration)* (Mitigated) 3 *(As above)*	 2 *(Very Unlikely)* 1 *(Almost No Likelihood)*	 **6** ***(Low Risk)*** **3** ***(Very Low Risk)***	2020

4 Recommendation

4.1 Preferred option

The preferred option is Option 3, which includes the extension and upgrading of Ergon Energy's existing PQ monitoring capability, alongside traditional solar PV augmentation works necessary to respond to areas of non-compliant network. Extending the PQ monitoring capability to a further 1.5% of distribution transformers unlocks significant potential benefits for Ergon Energy. The ability to better monitor, plan, and address PQ issues in the network will allow the distribution network to cope with the rapid uptake of solar PV and other distributed energy resources. This option is aligned with EQL's PQ strategies, future technology strategies, and customer engagement.

4.2 Scope of preferred option

The scope of works planned for Option 3 is outlined in Table 15, and highlights the forecast works under the two initiatives and their component programs.

Table 15: Scope of Works for Preferred Option 2

Program	Activity	2020/21	2021/22	2022/23	2023/24	2024/25	2020-2025 Total
PQ Monitoring	PQ Monitors to be installed	270	300	300	300	270	**1,440**
	PQ Analysers to be installed	3	5	5	5	3	**21**
Solar PV Augmentation	MV line regulators to be installed	10	12	4	4	2	**32**
	Low voltage regulators to be installed	60	60	100	115	115	**450**

The annual CAPEX associated with Option 3 is outlined in Table 16, in real 2018/19 dollars. The total CAPEX spend planned for the program in the next regulatory period is $15,657,400.

Table 16: Planned Annual CAPEX Spend Under Option 3 Program

Proposal Activity	2020/21	2021/22	2022/23	2023/24	2024/25	2020-2025 Total
PQ Monitoring						
PQ Monitors to be installed	$810,000	$900,000	$900,000	$900,000	$810,000	**$4,320,000**
PQ Analysers to be installed	$106,200	$177,000	$177,000	$177,000	$106,200	**$743,400**
Total	**$916,200**	**$1,077,000**	**$1,077,000**	**$1,077,000**	**$916,200**	**$5,063,400**
Solar PV Augmentation						
MV line regulators	$1,145,000	$1,374,000	$458,000	$458,000	$229,000	**$3,664,000**
Low voltage regulators	$924,000	$924,000	$1,540,000	$1,771,000	$1,771,000	**$6,930,000**
Total	**$2,069,000**	**$2,298,000**	**$1,998,000**	**$2,229,000**	**$2,000,000**	**$10,594,000**
TOTAL	**$2,985,200**	**$3,375,000**	**$3,075,000**	**$3,306,000**	**$2,916,200**	**$15,657,400**

Appendix A. References

Note: Documents which were included in Energy Queensland's original regulatory submission to the AER in January 2019 have their submission reference number shown in square brackets, e.g. Energy Queensland, *Corporate Strategy [1.001], (31 January 2019).*

AEMC, *Integrating Distributed Energy Resources for the Grid of the Future, Economic Regulatory Framework Review,* (26 September 2019).

Energy Queensland, *Asset Management Overview, Risk and Optimisation Strategy [7.025]*, (31 January 2019).

Energy Queensland, *Customer Quality of Supply Strategy [7.047],* (31 January 2019).

Energy Queensland, *Corporate Strategy [1.001],* (31 January 2019).

Energy Queensland, *Future Grid Roadmap [7.054],* (31 January 2019).

Energy Queensland, *Intelligent Grid Technology Plan [7.056],* (31 January 2019).

Energy Queensland, *Low Voltage Network Monitoring Strategy [7.080],* (31 January 2019).

Energy Queensland, *Network Risk Framework*, (October 2018).

Ergon Energy, *Distribution Annual Planning Report (2018-19 to 2022-23) [7.049]*, (21 December 2018).

Appendix B. Acronyms and Abbreviations

The following abbreviations and acronyms appear in this business case.

Abbreviation or acronym	Definition
$ nominal	These are nominal dollars of the day
$ real 2019-20	These are dollar terms as at 30 June 2020
2020-25 regulatory control period	The regulatory control period commencing 1 July 2020 and ending 30 Jun 2025
ACR	Automatic Circuit Recloser
ADMS	Advanced Distribution Management System
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
BCR	Benefit Cost Ratio
CAPEX	Capital Cost
Current regulatory control period or current period	Regulatory control period 1 July 2015 to 30 June 2020
DAPR	Distribution Annual Planning Report
DER	Distributed Energy Resources
DERMS	Distributed Energy Resources Management System
DNSP	Distribution Network Service Provider
EQL	Energy Queensland
EV	Electric Vehicles
HV	High Voltage
KRA	Key Result Areas
LV	Low Voltage
MAIFIe	Momentary Average Interruption Event Frequency Index event
MDI	Maximum Demand Indicator
MSS	Minimum Service Standards
MV	Medium Voltage
Next Regulatory Control Period	The regulatory control period 2020/21 to 2024/25
NER	National Electricity Rules
NPV	Net Present Value
OH	Overhead
OPEX	Operating Cost
PCBU	Person in Control of a Business or Undertaking

Abbreviation or acronym	Definition
PQ	Power Quality
Previous regulatory control period or previous period	Regulatory control period 1 July 2010 to 30 June 2015
PV	(Solar) Photovoltaic
QLD	Queensland
QoS	Quality of Supply
Regulatory Proposal	Ergon Energy's proposal for the next regulatory control period submitted under clause 6.8 of the NER
SAIDI	System Average Interruption Duration Index
SAIFI	System Average Interruption Frequency Index
SCADA	System Control and Ancillary Data Acquisition
STPIS	Service Target Performance Incentive Scheme
WACC	Weighted Average Cost of Capital

Appendix C. Alignment with the National Electricity Rules (NER)

The table below details the alignment of this proposal with the NER capital expenditure requirements as set out in Clause 6.5.7 of the NER.

Table 17: Alignment with NER

Capital Expenditure Requirements	Rationale
6.5.7 (a) (2) The forecast capital expenditure is required in order to **comply with all applicable regulatory obligations or requirements** associated with the provision of standard control services	As indicated in *Table 2: Compliance obligations related to this proposal*, this proposal ensures that safety obligations, reliability obligations and protection requirements are met by providing an appropriate, economically efficient program of works to ensure that the instance and impact of Power Quality issues can be managed effectively. Without this program, these obligations would be at risk of being breached.
6.5.7 (a) (3) The forecast capital expenditure is required in order to: (iii) maintain the **quality, reliability and security of supply** of supply of standard control services (iv) maintain the **reliability and security of the distribution system** through the supply of standard control services	This program of work directly addresses Power Quality issues which impact the quality of supply of standard control services. Network augmentation and remediation works and extended PQ monitoring capability are used to better analyse, understand, and respond to quality of supply issues which impact customer service and can result in non-compliance.
6.5.7 (a) (4) The forecast capital expenditure is required in order to maintain the **safety of the distribution system** through the supply of standard control services.	This proposal ensures that the safety or the distribution system is maintained by reducing the risk associated with power quality and voltage non-compliance issues.
6.5.7 (c) (1) (i) The forecast capital expenditure reasonably reflects the **efficient costs** of achieving the capital expenditure objectives	The options considered in this proposal take into account the need for efficiency in delivery and use historical programs of work as a basis for cost estimates. The preferred option has utilised a delivery approach that provides for bundling of work in terms of both timing and geography to enable a lower cost delivery. Specialised contractors are utilised as appropriate to ensure that costs are efficiently managed through market testing. Cost performance of the program will be monitored to ensure that cost efficiency is maintained. The unit costs that underpin our forecast have also been independently reviewed to ensure that they are efficient (Attachments 7.004 and 7.005 of our initial Regulatory Proposal).
6.5.7 (c) (1) (ii) The forecast capital expenditure reasonably reflects the costs that **a prudent operator** would require to achieve the capital expenditure objectives	The prudency of this proposal is demonstrated through the options analysis conducted. The prudency of our CAPEX forecast is demonstrated through the application of our common frameworks put in place to effectively manage investment, risk, optimisation and governance of the Network Program of Work. An overview of these frameworks is set out in our Asset Management Overview, Risk and Optimisation Strategy (Attachment 7.026 of our initial Regulatory Proposal).

Appendix D. Mapping of Asset Management Objectives to Corporate Plan

This proposal has been developed in accordance with our Strategic Asset Management Plan. Our Strategic Asset Management Plan (SAMP) sets out how we apply the principles of Asset Management stated in our Asset Management Policy to achieve our Strategic Objectives.

Table 1: "Asset Function and Strategic Alignment" in Section 1.4 details how this proposal contributes to the Asset Management Objectives.

The Table below provides the linkage of the Asset Management Objectives to the Strategic Objectives as set out in our Corporate Plan (Supporting document 1.001 to our Regulatory Proposal as submitted in January 2019).

Table 18: Alignment of Corporate and Asset Management objectives

Asset Management Objectives	Mapping to Corporate Plan Strategic Objectives
Ensure network safety for staff contractors and the community	EFFICIENCY ***Operate safely as an efficient and effective organisation*** Continue to build a strong safety culture across the business and empower and develop our people while delivering safe, reliable and efficient operations.
Meet customer and stakeholder expectations	COMMUNITY AND CUSTOMERS ***Be Community and customer focused*** Maintain and deepen our communities' trust by delivering on our promises, keeping the lights on and delivering an exceptional customer experience every time
Manage risk, performance standards and asset investments to deliver balanced commercial outcomes	GROWTH ***Strengthen and grow from our core*** Leverage our portfolio business, strive for continuous improvement and work together to shape energy use and improve the utilisation of our assets.
Develop Asset Management capability & align practices to the global standard (ISO55000)	EFFICIENCY ***Operate safely as an efficient and effective organisation*** Continue to build a strong safety culture across the business and empower and develop our people while delivering safe, reliable and efficient operations.
Modernise the network and facilitate access to innovative energy technologies	INNOVATION ***Create value through innovation*** Be bold and creative, willing to try new ways of working and deliver new energy services that fulfil the unique needs of our communities and customers.

Appendix E. Risk Tolerability Table

Network Risks - *Risk Tolerability Criteria and Action Requirements*				
Risk Score	Risk Descriptor	Risk Tolerability Criteria and Action Requirements		
30 – 36	***Intolerable*** *(stop exposure immediately)*			
24 – 29	***Very High Risk***	***ALARP** Risk in this range managed to As Low As Reasonably Practicable	**Executive Approval** (required for continued risk exposure at this level)	May require a full Quantitative Risk Assessment (QRA) Introduce new or changed risk treatments to reduce level of risk Periodic review of the risk and effectiveness of the existing risk treatments
18 – 23	***High Risk***		**Divisional Manager Approval** (required for continued risk exposure at this level)	Introduce new or changed risk treatments to reduce level of risk Periodic review of the risk and effectiveness of the existing risk treatments
11 – 17	***Moderate Risk***		**Group Manager / Process Owner Approval** (required for continued risk exposure at this level)	Introduce new or changed risk controls or risk treatments as justified to further reduce risk Periodic review of the risk and effectiveness of the existing risk treatments
6 – 10	**Low Risk**			
1 to 5	***Very Low Risk***		No direct approval required but evidence of ongoing monitoring and management is required	*Periodic review of the risk and effectiveness of the existing risk treatments*

SFAIRP Risks in this area to be mitigated So Far as is Reasonably Practicable

Figure 6: A Risk Tolerability Scale for evaluating Semi-Quantitative risk score

Appendix F. Reconciliation Table

Reconciliation Table Conversion from $18/19 to $2020	
Business Case Value	
(M$18/19)	$15.60
Business Case Value	
(M$2020)	$16.14

Appendix G. Supporting Information on Uptake of Small-Scale Solar PV

At the MV and HV levels, Ergon Energy has connected more than 250MW from Solar Farms (greater than 5MW) in the last year and there are currently more than 500MW of applications awaiting approval for possible connection. Figure 7 shows the grid connected Solar PV installed capacity for Ergon Energy's network.

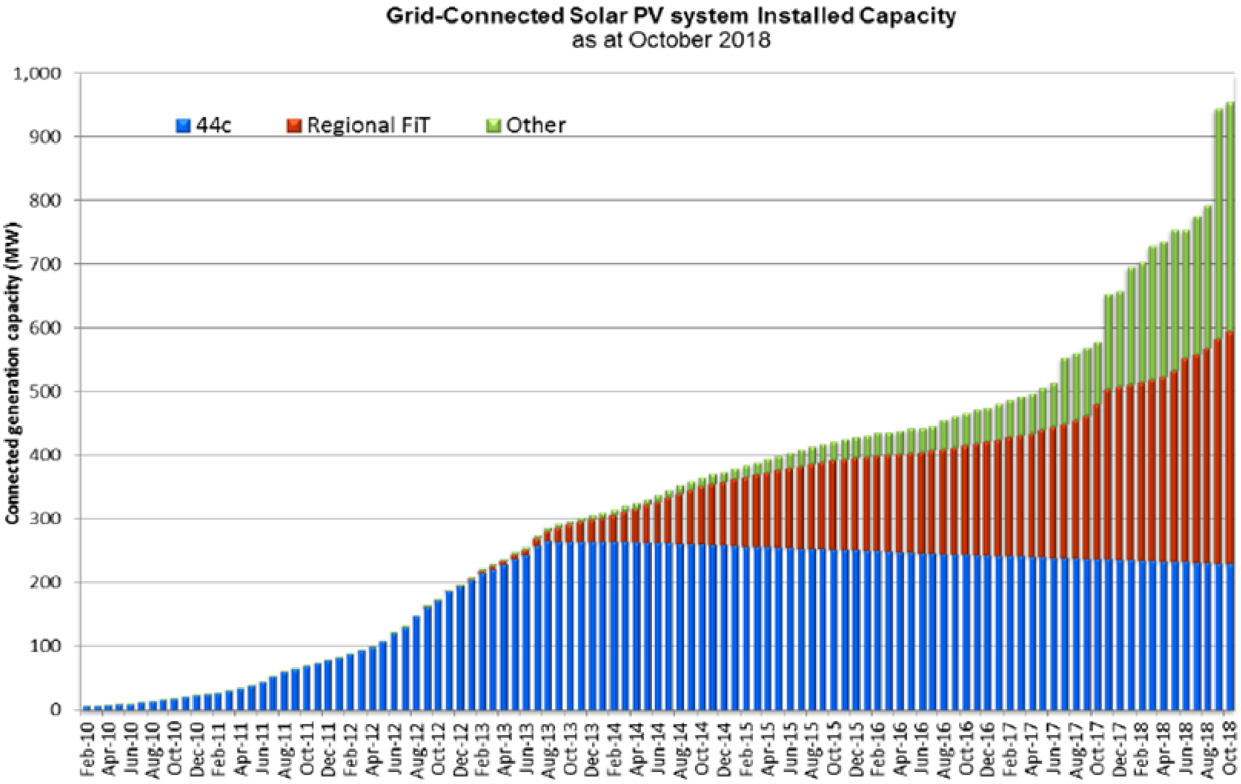

Figure 7: Ergon Energy grid connected Solar PV system installed capacity

Ergon Energy currently has in excess approximately 98,000 distribution transformers with individual sizes ranging from 5kVA to 1500kVA in capacity. Approximately 32% of these have Solar PV connected to them. 13% of the total population of the distribution transformers have PV penetration greater than 25% of the nameplate rating which results in reverse power flow back onto the HV during peak solar periods of the day.

Table 19 shows the analysis of the Solar PV systems connected to these transformers by the percentage of distribution transformer rating. The data shows that 15.1% of all single and three phase (Non SWER) transformers have more than 25% of their capacity in Solar PV connected. For the SWER transformer fleet, 7.06% have more than 25% of their capacity in Solar PV. Of the remainder of the transformer fleet, there are approximately 20,100 transformers with total Solar PV connected less than 25% of transformer rating and approximately 67,000 transformers with no Solar PV connected to them.

Table 19: Solar PV penetration as a percentage of distribution transformer ratings

Distribution Transformer Types	Total Count	>75% of Tx Rating	>50 - 75% of Tx Rating	>25 - 50% of Tx Rating	% Total of Distribution Tx
SWER	23,960	0.94%	1.24%	4.88%	2%

Distribution Transformer Types	Total Count	>75% of Tx Rating	>50 - 75% of Tx Rating	>25 - 50% of Tx Rating	% Total of Distribution Tx
1-3 Phase	74,224	3.09%	2.10%	9.91%	11%

Figure 8 shows a breakdown of the customer enquiries received by the reported symptoms over the 12 months up to June 2018, with the largest identifiable category, at 56%, related to quality of supply complaints due to Solar PV issues. Since 2013 the percentage of Quality of Supply (QoS) enquiries (complaints) across the Ergon Energy networks for Solar PV related issues have ranged from 40% to 56% of all QoS enquires.

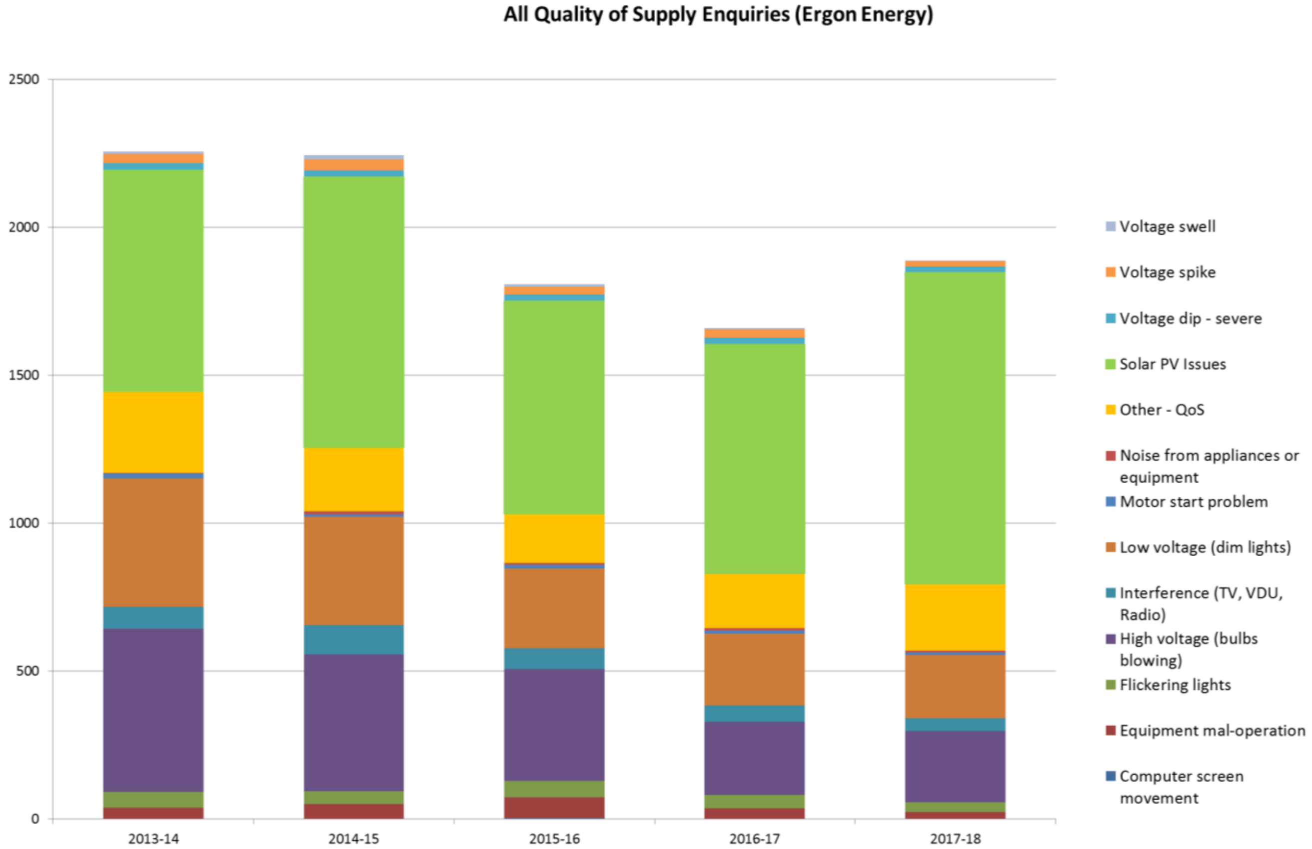

Figure 8: Number of all QoS enquiries at Ergon Energy by complaint types

The current augmentation works utilised to address PQ issues range from conductor changes and/or upgrades, transformer upgrades, regulator re-configuration changes and the installation equipment such line regulators, low voltage regulators (LVR) and Statcoms in local areas where no other option is available.

High penetrations of PV cause voltage rise and unbalance on MV feeders and LV circuits. At the ends, customers increasingly suffer from curtailment associated with the Vnom-max setting. This setting only became available following the release of AS/NZS4777.2:2015 and became mandated by Ergon Energy's connection standards from 30 September 2015. This was also when reactive power compensation requirements were introduced to help mitigate voltage rise. Inverters installed prior to this that remain the majority of the connected PV population, were required to be compliant with the earlier AS4777.3:2005, which specifies a Vmax setting which can be as high as 270V despite Ergon Energy's requirements specifying 255V.

Currently Ergon Energy species a value of 255V for Vnom-max which allows for up to 2V rise above 253V in customer premises. When inverters breach this limit for 10 minutes they disconnect. Where voltage rise between inverter and Point of Common Coupling (PCC) is less than 2V, the 255V limit allows voltages greater than 253V to be impressed on the network, requiring remediation. Reducing this value down to <255V, in line with AS/NZ4777.2, default for all new PV connections would reduce the likelihood of network overvoltage from new systems but would significantly increase curtailment of end customers and associated QoS enquiries. It should be noted that the Ergon Energy networks are particularly at risk from over-voltages and/or customer curtailment due to the weaker, radial and longer LV and MV networks present within the distribution area. The preferred upper operating range that Energy Queensland is aiming for is 246V. By operating the network at or below 246V will allow more customer solar PV systems to be connected to the network without impacting other customers on the same LV network.