Customer Quality of Supply

Part of the Energy Queensland Group

Executive Summary

The quality of electricity supply provided to customers can be affected by a multitude of causes and can affect customers in various ways. Queensland Electricity Regulations and the National Electricity Rules specify network performance requirements to be achieved by Network Service Providers (NSPs). The most relevant requirements from a power quality perspective are specified against the following network characteristics:

- Magnitude of power frequency voltage
- Voltage fluctuations
- Voltage harmonic distortion
- Voltage unbalance

If the network provider provides power quality which is outside the specified requirements of these characteristics, customers connected electrical equipment may not operate as intended, or in the worst cases provide unsafe conditions to customers as a result of potential shock exposure hazards and risks to customer equipment. Power quality issues also result in customers making enquiries to their respective network provider, who then reactively investigate the issue and implement solutions on a localised basis.

Quality of Supply (QoS) has always been an issue requiring careful consideration and management by electricity network providers. However, more recently, customers are connecting new technologies such as solar PV, batteries and electric vehicles (EVs). Energy Queensland supports and encourages its customers adopting these new technologies. However, these innovations have the potential to impact network power quality.

To this end, Energy Queensland has developed this Customer Quality of Supply Strategy. A key focus of the strategy is on maintaining customer and network safety, minimising QoS complaints and risks of damage to customer equipment from voltage outside statutory limits arising from the impact of high solar PV penetration, as well as the other influencing factors outlined above.

Energy Queensland's Customer Quality of Supply Strategy is made up of five key concepts. These are, in order of priority:

1. Monitoring & data analytics
2. Investigations and options analysis
3. Customer connection standards
4. Intelligent grid solutions
5. Rectification works

The strategy is designed to achieve the following high-level objectives:

- Compliance to statutory requirements and core obligations to manage power quality parameters of the network

- Expected business outcomes and fulfilment of stakeholder expectations by ensuring the network is 'fit for purpose' to accommodate changing customer energy usage patterns and increased penetration levels of distributed energy resources
- Balanced commercial outcomes by ensuring the investment in the LV network is optimised to address risk, cost and performance.
- Balance commercial outcomes by ensuring the investment in the MV and HV network is optimised to address the risk, cost and performance for customers connected at these levels.

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Document Approvals

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Contents

1. Introduction

Power quality (PQ) problems can be defined as any power problem manifested by voltage, current, and frequency deviations that result in failure or maloperation of load or equipment. PQ problems may be classified into two categories: (1) conducted low-frequency phenomena and (2) radiated frequency phenomena.

The conducted low-frequency phenomenon is characterized by the following types of PQ problems:

- Overvoltage, undervoltage, transients including sags and swells
- Voltage fluctuations (flicker)
- Voltage dips and interruptions
- Voltage imbalance or unbalance
- Power frequency variations
- Induced low-frequency voltages
- Harmonics, interharmonics, and harmonic resonance.

The radiated frequency phenomenon known as noise is characterized by the following types of PQ problems.

- Magnetic and electric fields (electromagnetic interference, EMI)
- Radio frequency interference (RFI)

Further, the addition of nonlinear (digital and electronic) loads in industrial and commercial power systems have led to problems in the quality of power that is being delivered to a site. A nonlinear load is defined as that which draws a nonsinusoidal current wave when supplied by a sinusoidal voltage source.

PQ problems can produce results that range from erratic equipment behaviour to complete shutdown of a facility. In some cases, the shutdown may be accompanied by a catastrophic failure costing millions of dollars in some cases. Thus, it is important to understand and solve PQ problems. Also, PQ problems can creep along silently consuming maintenance resources for troubleshooting PQ anomalies and at the same time increasing the cost of electrical energy because of inefficient use.

PQ covers a wide range of issues, from voltage disturbances like sags, swells, outages and transients, to voltage and current harmonics, to the performance of wiring and grounding. The concept of load and source compatibility is not new. The need to provide power with steady voltage and frequency was recognized since the early days of the electrical power. Some of the early concerns were flicker of light bulbs due to voltage fluctuations and overheating of motors due to voltage waveform distortion (harmonics). More recently, transient voltage disturbances associated with lightning and power system switching have emerged as a major concern to manufacturers and users of electronic equipment.

Today's PQ problems are far more complex. They cannot be handled so easily because of a multitude of different causes and a variety of specific sensitivities in the end user equipment that is most affected. Because both the causes and consequences of PQ problems are so diverse, they are not amenable to a single solution.

This strategy outlines the current customer Quality of Supply (QoS) obligations, environment, drivers and future requirements for Energy Queensland. Customer expectations are increasing as new technologies such as solar Photovoltaics (PV), batteries and electric vehicles become more widespread. These technologies have the potential to cause increased disturbances in the supply network if not properly planned for and accommodated. Disturbing loads have been successfully managed for as long as electricity networks have existed. With more advanced forms of monitoring and data analytics network power quality risks associated with existing and new disturbing loads can be managed. This will ensure the benefits associated with new technologies can be enjoyed as widely as possible across the community.

Energy Queensland's Future Grid Roadmap provides direction for the development of an intelligent grid. This document lays out a customer centred pathway for developing advanced systems to monitor, predict and coordinate system inputs and outputs down to the LV level to support the integration of very high penetrations of distributed energy resources (DER) such as solar PV. It builds on the Electricity Network Transformation Roadmap (ENTR), produced by Energy Networks Australia (ENA) and CSIRO in 2017.

2. EQL Power Quality CAPEX Program

Energy Queensland Strategic Plan addresses the Power Quality current obligations, environment, drivers and future requirements, focussing on voltage management on the HV and LV networks. One of the key power quality challenges addressed in this Strategic Plan arises from the high penetration of customer solar photovoltaic (PV) systems.

As a result, we have identified the following areas as common EQL PQ strategies:

- Data acquisition systems to collect, store and present data
- Real-time data analysis and reporting systems to identify network problems
- Real-time alarms, control and analytics to integrate into enhanced operational systems
- Enhance current network models and develop network models down to LV
- Trail new technologies for remediation of PQ issues
- Proactively address emerging PQ issues.

The implementation of these strategies will meet several objectives with some of the key ones being:

- Greater observability of the MV and LV networks.
- Transition the 230V standard for improved voltage management
- Improved data delivery for model validation and PQ reporting
- Capacity of the network to host greater embedded generation and controlled loads.

- Minimising customer complaints and damage to customers equipment
- Low Voltage network issues due to Generation (Solar PV), customer batteries and neutral current and integrity
- Solar Farm connections
- Ability to report on momentary outages.

With these objectives, our PQ CAPEX plans for 2020-2025 address current Power Quality obligations and statutory requirements, power quality issues caused by increasing penetration of PV systems on our networks and greater voltage regulation to be managed.

3. Influencing Factors

There are several factors which either influence the quality of electrical supply provided by the network or are drivers for effective management of quality of supply. These factors are explained further below.

3.1 Customer Safety

The predominant driver for maintaining quality of supply is safety to customers. Inadequate quality of supply and other network issues can result in potential shock exposure hazards and risks to customer equipment. This may include voltages outside of statutory limits or impacts on the integrity of Energy Queensland's neutral system due to ageing networks and environmental factors.

3.1.1 Power Quality Supply Standards, Codes and Guidelines

Queensland Electricity Regulations and the National Electricity Rules specify network performance requirements to be achieved by Network Service Providers (NSPs). The most relevant requirements from a Power Quality perspective are specified against the following network characteristics:

- Magnitude of power frequency voltage
- Voltage fluctuations
- Voltage harmonic distortion
- Voltage unbalance

3.1.2 Queensland's Statutory Voltage Limit Review

In October 2017 the Queensland Government executive council approved the Electricity (Voltage Limits) Amendment Regulation 2017, introducing the adoption of AS60038 (Standard Voltages) and AS61000.3.100 (Limits – Steady State Voltage Limits in Public Electricity Systems) in Queensland. As part of this amendment, it stipulates a transition for compliance with AS60038 be completed by 26 October 2018, and broad adoption of AS61000.3.100 to be completed by 30 June 2020.

Under previous Queensland regulations, the nominal voltage for low voltage (LV) supply was 240 volts, with an allowable margin of +/- 6%. AS60038 currently sets the standard voltage at 230 volts with an allowable margin of +10%/-6%. AS61000.3.100 then specifies a preferred median (or V50%) voltage performance between 225 and 244 volts, based on consecutive 10-minute average measurements taken for at least one week. The upper and lower limit preferences are based on 99th and 1st percentiles (V99% and V1%) using the same measurement principles.

Energy Queensland has commenced the transition to the new voltage standards via a phased approach:

- Phase 1 is to achieve initial compliance with the new statutory voltage limits (216V to 253V) on the LV network by October 2018. This is to be achieved through a reduction in Medium Voltage (MV) levels through targeted updating of zone substation voltage regulation parameters. All zone substations in Energy Queensland will be reviewed, whilst regional zone substations to be reviewed will be prioritised based on several criteria.

- Phase 2 is to carry out a short-term optimisation to begin to align voltage levels with the preferred voltage band as much as possible. This will be achieved by targeted distribution transformer tap changes where necessary by 2020, as well as ongoing tap changes during normal activities. Zone substation voltage regulation setting changes will be applied to the next prioritised substations in regional areas.

- Phase 3 is long term optimisation during business as usual activities. Any remaining regional zone substations will have their MV levels reviewed and updated. A program to review zone substations on a cyclical basis will be undertaken. Distribution transformers will continue to have their taps aligned with the relevant local tap plan during any scheduled activities which allow access to affect a tap change.

Expected customer benefits from the lower preferred supply voltages of the 230V standard include:

- reduced Solar PV inverter tripping on high voltage

- improved equipment performance

- small energy savings

- alignment with national and international best practice standards

The 230V standard will also result in a decreased requirement for augmentation and rectification works on Energex and Ergon Energy’s networks. This has been reflected at a high level in future programs of work. However, a more detailed analysis is required to confirm the impacts.

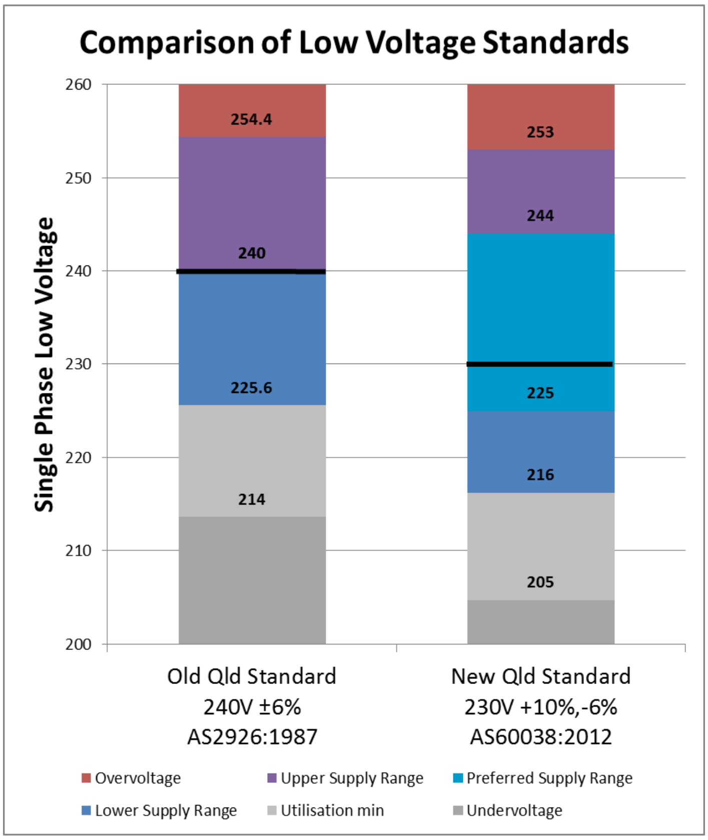

Figure 1 – Comparison of Low Voltage Standards

3.1.3 Voltage Fluctuations

Voltage fluctuations that are within the control of ENERGEX and Ergon Energy arise from switching plant such as capacitor banks, reactors and power transformers into or out of service. The magnetising inrush currents that result when unloaded power transformers are energised may also be problematic. Figure 6 shows the typical 66 kV current waveform that can be anticipated in the first 0.5 seconds after an unloaded 25 MVA 66/11 kV transformer is energised.

Although the duration of the large currents is short, the resultant voltage drop may be an issue for other customers.

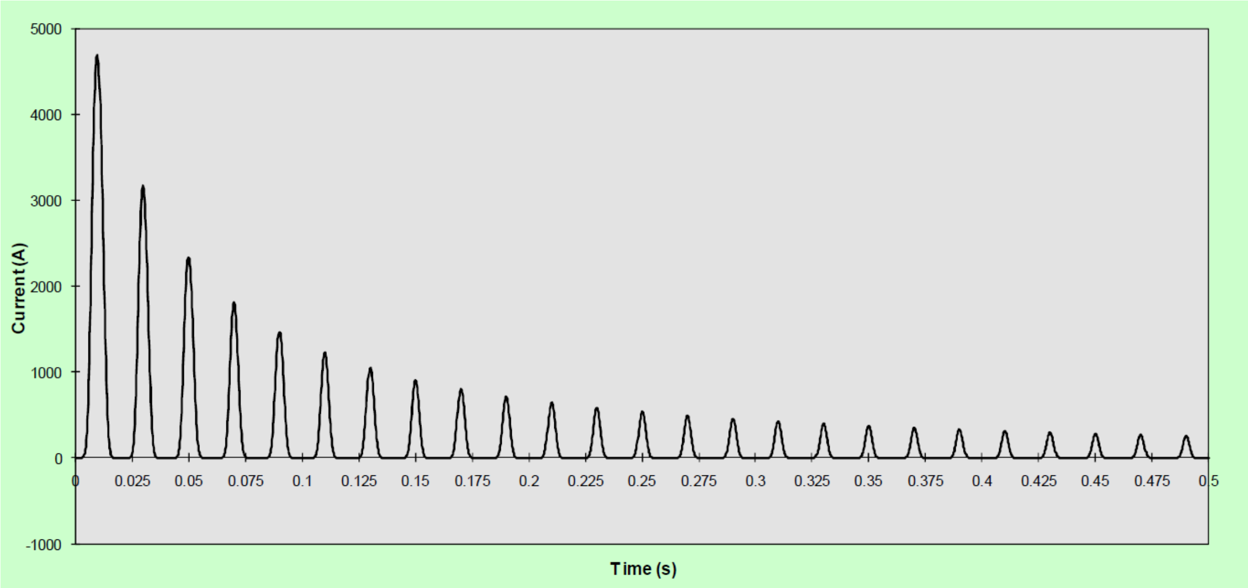

Figure 2 – Typical 25MVA Transformer Energisation Magnetising Inrush Current

3.1.4 Voltage Imbalance

A voltage imbalance is a long term, steady state problem caused by unbalanced phase loading conditions, defective transformers, and ground faults in ungrounded or resistive grounded systems. These imbalances usually are caused by large single-phase loads. They cause premature failures of motors and transformers due to overheating.

Ideally, the phase to connect a new customer to should be determined by logging the existing load on the circuit to which they are to be connected. Together with knowledge of the new customer's load magnitude and profile, a decision can then be made on which phase to connect the new customer so that load is balanced as well as possible.

3.1.5 Harmonic Distortion

Harmonics are voltages or currents at frequencies that are integer multiples of 60 Hz frequency (120, 180, 240, 300 Hz, etc.). They are designated by their harmonic number or multiple of the fundamental frequency. For example, a harmonic with a frequency of 180 Hz— (three times the 60 Hz fundamental frequency) is called the third harmonic. As shown in Figure 3, harmonics superimpose themselves on the fundamental waveform, distort it, and change its waveform. In industrial power systems, for example, 15%, 20%, or 25% total harmonic current distortion (THD) may be experienced.

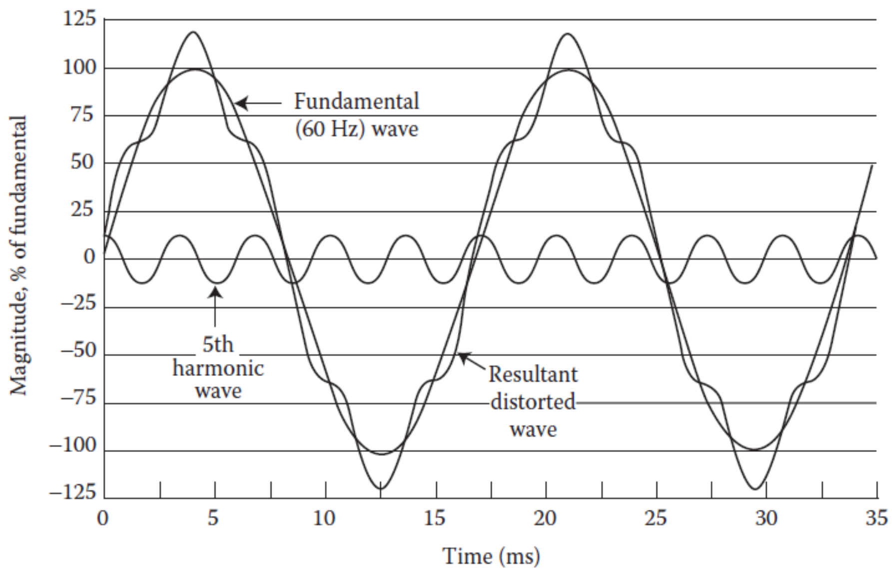

Figure 3 – Harmonic Distortion Caused by 5th Harmonic Current

Harmonics can cause overloading of conductors and transformers and overheating of utilisation equipment, such as motors. Odd-numbered triplen harmonics (3rd, 9th, 15th, etc.) can especially cause overheating of neutral conductors on three-phase, four-wire systems. While the fundamental frequency line currents and other even harmonic currents cancel each other in the neutral, the triplen harmonic and other odd harmonic currents are additive in the neutral. Harmonics also can cause tripping of circuit breakers.

3.1.6 Distribution Networks and Excessive Voltages

Long rural networks with relatively high impedance may be subject to overvoltage when a large proportion of their load is lost due to the operation of automatic protection equipment.

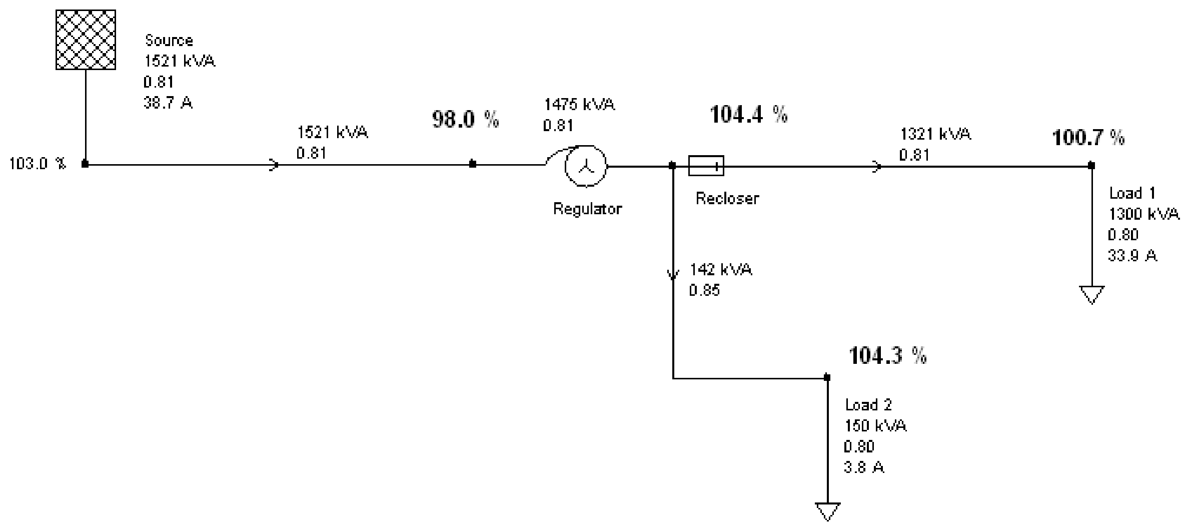

Figure 4 – Sample Distribution Network

Figure 4 shows a simple example distribution feeder network supplying two loads via a regulator. Load 1 is relatively large and electrically far from the regulator. Load 2 is much smaller and quite close to the regulator. Under normal conditions, both loads are supplied with voltage in the normal range, with Load 1 seeing 100.7% of nominal and Load 2 sees 104.3%. However, if the recloser in the network opens, the load on the network will reduce dramatically, and there will be a corresponding increase in voltages.

Several issues need to be considered in this example, including:

- Duration of higher than normal voltages
- Value of the overvoltage.
- Likely impact on customers

The longer voltages outside than the normal range occur on the network, the more likely it is that there will be adverse impacts on customers' equipment. The range of acceptable voltage for short term effects such as load rejection is defined in the Voltage Management Standard as 90% to 114% of nominal voltage. Accordingly, the network should be designed so that if a recloser or circuit breaker trips during the most onerous loading conditions, supply voltage does not go outside this range. Voltage regulation equipment should be set to ensure that supply voltage returns to the normal range within one minute of the event.

A longer distribution network with more regulators in series may result in higher load rejection voltage rise than illustrated above. In these cases, the placement of reclosers in the network must be carefully considered to avoid subjecting customers to excessive voltage excursions during load rejection or pickup.

A similar phenomenon is also possible in rural zone substations where one heavily loaded feeder trips causing the transformer load to fall appreciably and the busbar voltage to rise for all remaining connected customers.

3.2 Customer Experience

One of the ways Energy Queensland measures the customer quality of supply experience is by the number of Quality of Supply enquiries it receives. These enquiries are broken down by the reported symptoms, with the most significant categories over the last 12 months being solar PV related, minor voltage dips, voltage swells and low supply voltage.

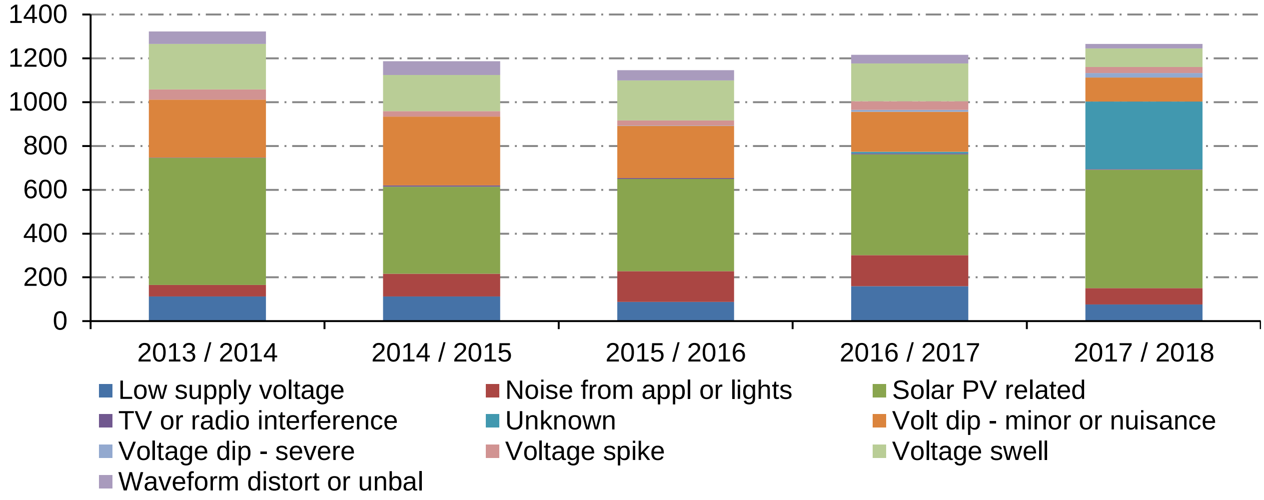

Figure 5 – Energex QoS Enquires (DAPR 2017/18-CH11)

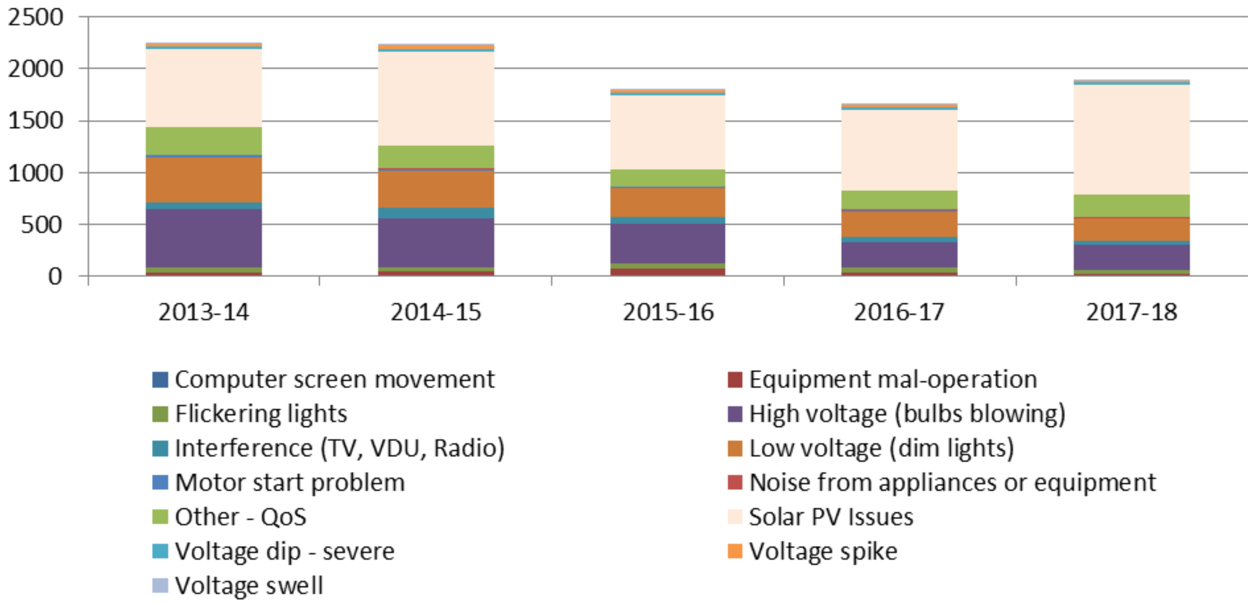

Figure 6 – Ergon Energy QoS Enquires (DAPR 2017/18-CH11)

3.3 Customer Impacts on Quality of Supply

Customers are changing the way they interact with the power network. For most of Energy Queensland's customers, affordability and reliability will remain their highest priority. For a growing number of customers, they also want the flexibility to actively participate in the electricity markets.

This includes self-generation, selling excess capacity back into the market or to specific individuals or third-parties, and to take advantage of innovative products and services that will become available. This is supported by feedback from the Queensland Household Energy Survey, where a significant percentage of customers across Queensland indicated that they intend to install solar PV during the next two years. The intention to install batteries is still relatively low, however many customers indicated that they would consider purchasing battery storage if the technology were more affordable.

Energy Queensland supports and encourages its customers adopting these new technologies. However, these innovations have the potential to impact network power quality. Hence the technology interactions between the customer and the network require careful consideration, and the network will have to be adapted over time to be able to continue to deliver a safe and reliable service with acceptable quality of supply. The Future Grid Roadmap provides customer-focused solutions in which customer expectations are met and network limitations are resolved collaboratively with tools such as Low Voltage (LV) orchestration, micro-grids and targeted demand management.

3.3.7 Solar PV (Low Voltage)

Queensland has the highest uptake of residential rooftop solar PV installations in Australia, and one of the highest per-capita in the world. Traditionally, distribution networks around the world were designed to accommodate the steady state voltage dropping with the flow of power from the High Voltage (HV) transmission system, ultimately through to the LV distribution system. With the connection of large numbers of residential solar PV systems on to the LV network (now exceeding 50% of detached homes supplied from some zone substations) in certain areas the power now flows upstream on sunny days in the shoulder seasons (spring and autumn). This reverse power flow is less predictable and leads to both voltage rise and voltage drop throughout the network having to be carefully managed to ensure voltage at customer terminals stays within statutory voltage limits.

Under Energy Queensland's network connection agreements for solar PV connections, customers through their installers are required to ensure that their inverter has its overvoltage trip settings configured correctly. This feature is designed such that the inverter trips out if the customer is experiencing voltages higher than this setting, resulting in the customer being unable to export electricity to the network or offset their own electricity usage with energy generated from the solar PV during this time. The Australian Energy Regulator's (AER's) final determination to Ergon Energy (2015-2020) accepts curtailment as the primary means of managing overvoltage associated with excessive generation from high penetrations of Solar PV, "we consider that, if Ergon Energy enforces the voltage cut-off requirements in its new connection standard, then new solar PV connections installed over 2015–20 should create very few overvoltage issues on Ergon Energy's network (FINAL DECISION Ergon Energy determination 2015−16 to 2019−20 Attachment 6 − Capital expenditure pp.6-57).

Therefore, Energy Queensland's management of steady state voltage through its quality of supply strategy is important to ensure that customers continue to both receive good quality of electricity supply and obtain maximum benefit from their investment in solar PV with minimal curtailment.

When planning the connection of embedded generation, of considerable size for LV installation (between 5-100kW) that could be connected to the LV distribution network consideration should be given to the overall impact this generation will have on the voltage regulation profile of the LV and HV distribution feeder.

Whilst most LV generation will be provided by the installation of Photovoltaic arrays on domestic rooftops, each considered to be approx. 1- 1.5kW typical installation, individually these will have a negligible effect on the voltage profile of the feeder.

However, precautions should be taken when considering the connection of several PV arrays that will be distributed along a single LV feeder from a distribution transformer or a larger connection of a single generator connected to an LV distributor, such as a small hydro scheme (these may be up to 30-50kW).

In either case, the possible impact and future implications of restrictions on the HV network may not be considered at the time of planning the connection. As there would be no contractual obligations between the generator and the NSP; the NSP must be able to control the voltage along the LV or HV feeder always, (i.e. with or without the generator exporting to the electricity network) and for the voltage to remain within statutory ranges.

3.3.8 Solar PV (Medium Voltage, High Voltage)

Since 2015, the Energy Queensland networks have experienced an exceptionally high number of applications to connect solar farms in regional areas. Each application requires planning and review to determine the impact on the existing network and analysis of the operation of the solar farm for compliance when connected. Applications for large scale generation (including solar farms) are expected to remain high in the coming years. Energy Queensland will monitor all solar farm connections to ensure that all power quality parameters remain compliant.

Energy Queensland has developed several connection standards for Solar PV connections from 30kW to greater than 5MW. These standards provide proponents with their obligations for connection and interfacing to the Energy Queensland networks.

3.3.9 Battery Energy Storage Systems

The awareness and intent to purchase Battery Energy Storage Systems (BESS) increased among Queensland customers with solar PV. Energy Queensland anticipates that this will continue as the technology matures and costs reduce. Many customers see BESS as a way to improve supply reliability, rather than reduce bill size, and very few Queensland households intend to go off grid in the near future. The uptake of BESS has the potential to provide benefits to both the customers and the distribution network if coordinated. From the network perspective, BESS could be called upon to support assets during peak demand periods or to mitigate power quality issues during high solar PV generation periods.

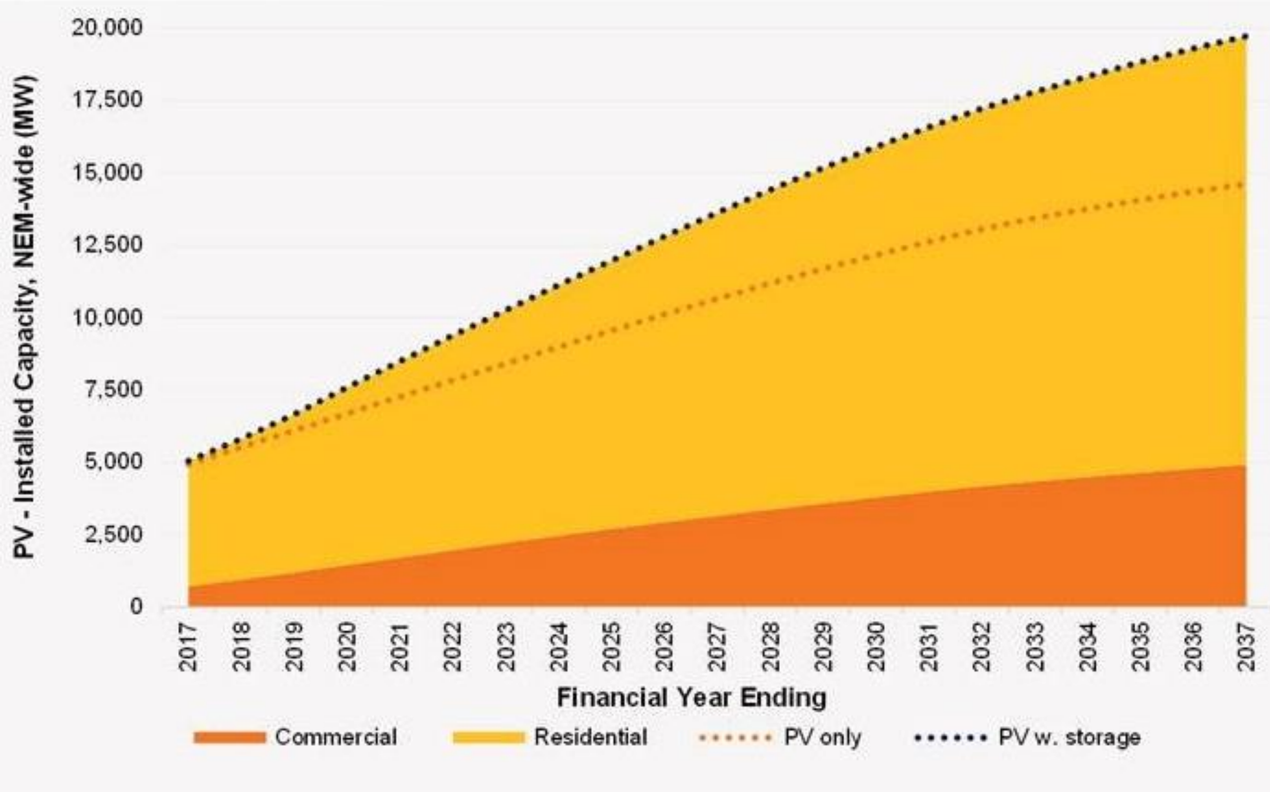

Figure 7 – AEMO PV and Battery Storage Forecast

(https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Electricity-Forecasting-Insights/2017-Electricity-Forecasting-Insights/Key-component-consumption-forecasts/PV-and-storage)

It is clear that customers' expectations of the network are changing, and Energy Queensland must accommodate these changes. A key challenge for Energy Queensland is identifying strategies to coordinate BESS to optimise benefits to the network and therefore reduce the cost to serve. These challenges include:

- Integration with existing control & operational systems;
- Limited engineering data measured on the LV network, where the majority of residential BESS will be installed; and
- Conflicting support requirements between customers, the network and even between different parts of the network.

Once BESS reaches significant penetration levels (>15%), further challenges will include identifying how these systems can be incorporated into planning and forecasting functions. As elucidated in the Future Grid Roadmap, network aware orchestration and aggregation will help ensure DER operation, including BESS, do not exacerbate network limitations.

3.3.10 Electric Vehicles

Plug-in Hybrid Electric Vehicles (PHEVs) and pure Electric Vehicles (EVs) are a growing class of electrical load that could have a significant impact on the LV electricity network. Battery capacity of currently available PHEV and EV models is in the range of 16kWh (Mitsubishi) to 100kWh (Tesla Model S). Tesla's fast EV charging station (known as Supercharger) is 120kW and capable of charging the Model S battery in just 40 minutes to 80% full capacity.

Currently, EV uptake in Australia is amongst the lowest in the Organization for Economic Cooperation and Development (OECD) countries. In 2017, EVs account for only 0.04% of registered cars in Queensland. The uptake rate of EVs in near future is not expected to increase rapidly due to factors such as lack of federal supporting policies, high capital cost and perceived range anxiety. However, investment in the Queensland Electric Super Highway may spur more interest in urban communities along the coast and rapid development of lithium-ion battery technology could be a game changer.

Energy Queensland has been monitoring the development of EVs and battery storage technology to better understand the impact of these emerging technologies on the distribution network. Energy Queensland has adopted a scenario-based approach for long term planning studies to deal with the uncertainty and forecast demand considering the high penetration of emerging technologies.

Single phase electric vehicle supply equipment (EVSE) poses a risk of increased voltage unbalance on weaker areas of the network and is thus limited to 20A. 3-phase EVSE should be promoted as they not only support higher speed charging but reduce voltage unbalance and neutral currents.

The aggregated impact of EVs on the HV network is not as significant as local capacity constraints on the LV distribution network. Uncontrolled EV charging can result in coincident charging of multiple EVs from a traditional LV feeder (which was designed originally to supply residential customers). Under this scenario, with a high penetration of EVs, significant network augmentation (such as transformer and feeder upgrades) will be required; this may consequently lead to higher electricity prices. However, intelligent EV charging in coordination with local network constraints – known as controlled EV charging – may avoid network augmentation, while still promoting energy sales revenue for distribution utilities and increased asset utilisation. Moreover, provided that electricity to charge the EVs is supplied from renewable sources, EVs provide health, environmental and fuel security benefits to the Australian community.

Another risk posed by the growth of EVs is the associated growth in scale and capacity of public charging infrastructure. Ratings are increasing from 3.6kW destination chargers at shopping centres; to 50kW fast chargers on the Queensland Electric Super Highway; to 120kW Tesla super chargers in banks of six; and now to 375kW chargers (rated to 475kW) in banks of six (fed from a 1.25MVA transformer) rolling out in the European Ionity network and planned for Australia. As the speed of charging increases, demand increases but becomes less consistent, creating a more spiky load profile which increases the risk of voltage sags and swells. While no direct mitigations for this are planned, the connections process ensures costs are borne by the applicant and demand charges may incentivise some level of buffering to mitigate the most extreme variations.

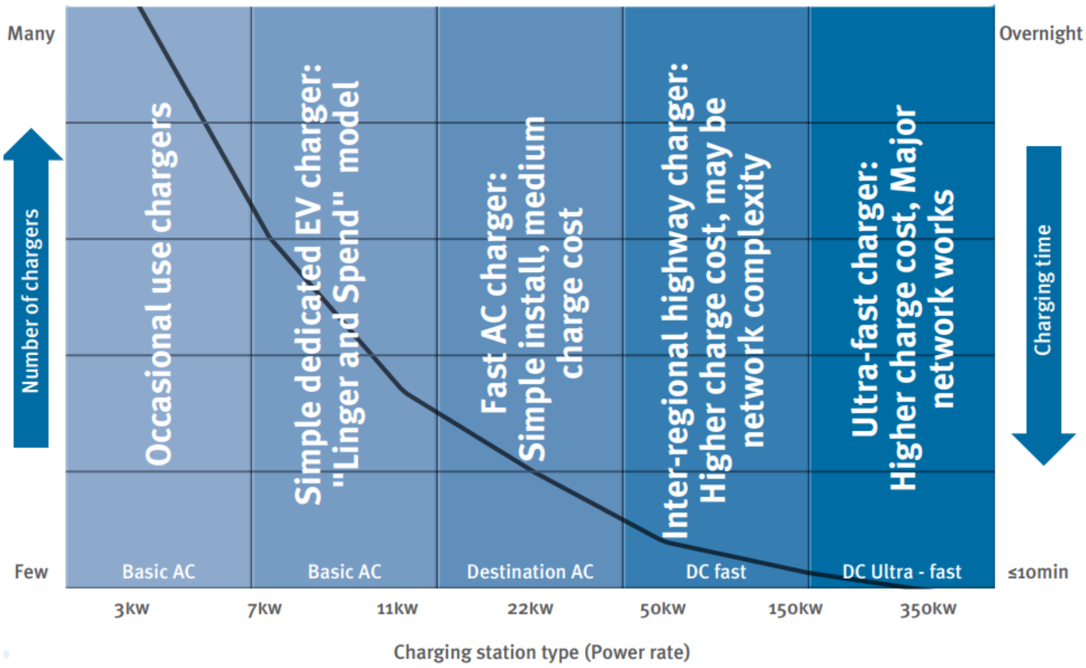

Figure 8 – EV SE Ecosystem Charging Curve

(https://www.dsdmip.qld.gov.au/resources/guideline/pda/guideline-electric-vehicles.pdf)

3.4 Future Grid Roadmap

The Customer Quality of Supply Strategy has been developed as part of Energy Queensland's overall Future Grid Roadmap. The next decade is likely to see a step change in the rapid adoption of new energy technologies, driven by falling costs and global carbon abatement measures. This decade provides a limited window of opportunity to reposition Energy Queensland and deliver more efficient outcomes to Queensland customers.

The agility with which networks connect, integrate and incentivise new, lower carbon energy choices will directly influence the cost, fairness, security and reliability of the electricity system for our customers. It is also expected that regulatory and policy changes will occur to maintain power system security while reducing customer costs by enabling the efficient use of DER, standalone systems and micro-grids. Timely development of technical standards and new platforms will allow new DER markets and permit more efficient customer services and participation.

In addition to Energy Queensland's Future Grid Roadmap, CSIRO and Energy Networks Australia (ENA) have developed the ENTR. This roadmap was developed to guide a structured transformation over the 2017-27 decade and to equip networks to deliver on the customer outcomes specified in the roadmap. Energy Queensland's Future Grid Roadmap and the Customer Quality of Supply Strategy support the ENTR, with specific consideration given to enhanced intelligence and decision-making tools, active network management and enabling the connection of customer DER.

4. Customer Quality of Supply Strategy

A key focus of the Customer Quality of Supply Strategy is on maintaining customer and network safety, minimising complaints and risks of damage to customer equipment from voltage outside statutory limits arising from the impact of high solar PV penetration, as well as the other influencing factors outlined above.

The strategy is designed to achieve the following high-level objectives:

- Compliance to statutory requirements and core obligations to manage voltage on the network
- Expected business outcomes and fulfilment of stakeholder expectations by ensuring the network is 'fit for purpose' to accommodate changing customer energy usage patterns and increased penetration levels of distributed energy resources
- Balanced commercial outcomes by ensuring the investment in the LV network is optimised to address risk, cost and performance.
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Energy Queensland's Customer Quality of Supply Strategy consists of five key concepts (Figure 6). These are, in order of priority:

1. Monitoring & data analytics
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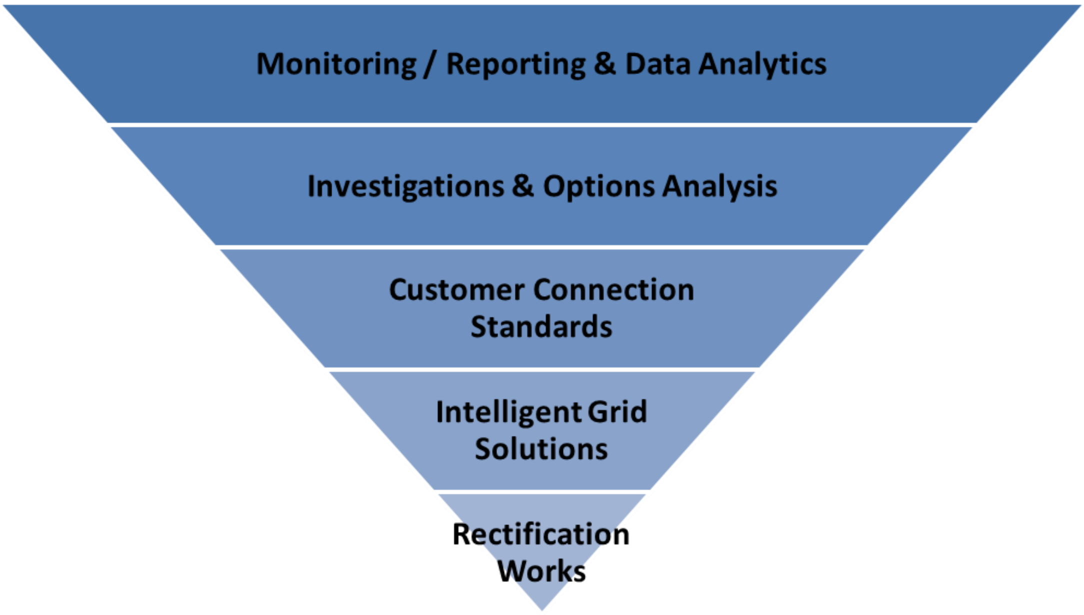

Figure 9 – Concept of EQL Customer QoS Strategy

These key concepts are explained further in the following sections.

4.1 Monitoring and Data Analytics

To achieve Energy Queensland's customer quality of supply objectives, it is proposed to continue with Energy Queensland's monitoring and data analytics programs. This will be made up of a combination of zone substation, MV feeder, distribution transformer, LV circuit, and customer monitoring. These programs allow greater observability of the networks from HV through to customer premises for improved analytics and data-driven decision making, as well as support the Future Grid Roadmap and ENA/CSIRO ENTR recommendation for enhanced intelligence and decision-making tools.

As part of the customer monitoring program, it is also proposed to implement neutral integrity monitoring at the LV level. This is a community safety initiative, which will provide a monitoring system to detect dangerous shock exposure hazards and bad joints that can cause equipment failure and line losses. At present these hazards are difficult to detect and usually only identified following a voltage or shock enquiry or network failure. This capability will require the utilisation of distribution monitoring and analytics to better quantify issues and target resources.

In future, this data may be able to be obtained at an individual customer level from third-party meter data providers, rather than continued installation of Energy Queensland network devices at customer premises. However, this market is currently quite immature, with several issues still to be determined, such as standard data formats, granularity, protocols, and definitions. The price and terms to provide this data is also still unknown. However, once this market has matured further, it is expected that a cost-benefit analysis can be done to determine whether this is an overall cheaper option to obtain customers' engineering data, where available.

The monitoring program will also assist to achieve and demonstrate compliance with AS61000.3.100, which specifies a methodology for measuring network voltage to meet the standard.

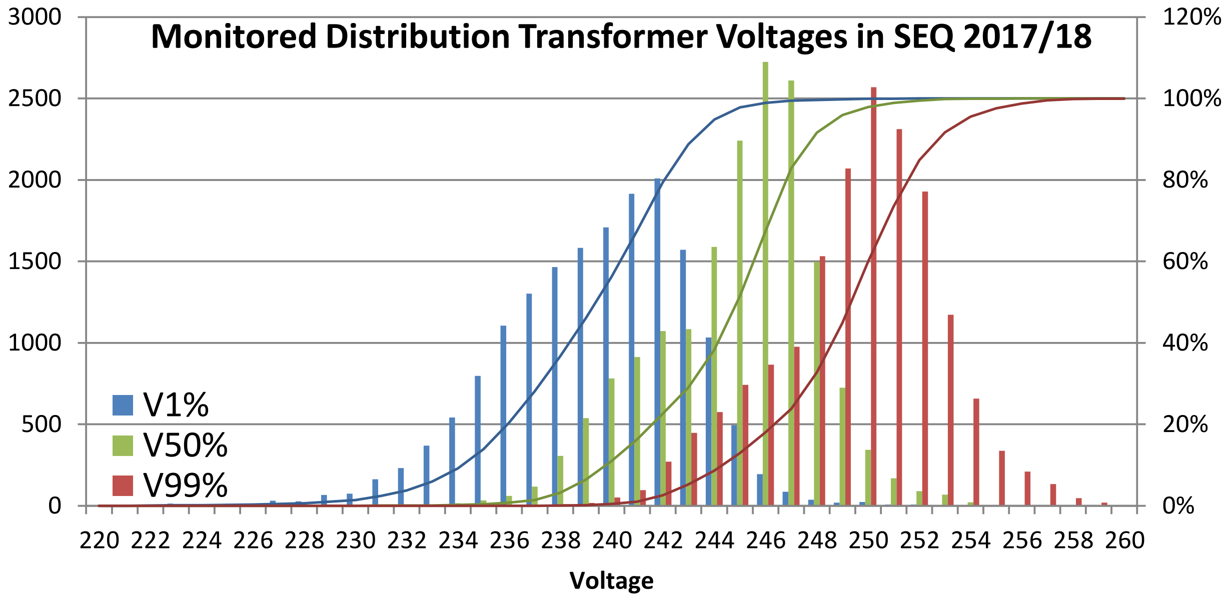

Figure 10 – Monitored Distribution Transformer Voltages in Energex 2017/18

4.2 Investigations and Options Analysis

The network data and analytics tools provide opportunities to carry out investigations to identify non-compliant areas of the network with respect to statutory voltages and network standards. It can also be used to carry out further analysis of network limitations and constraints potentially introduced through the connection of customer distributed energy resources. This may provide solutions which will allow the hosting capacity of the network to be increased, resulting in more DER connections to the network. These solutions could be location specific for short-term rectification or provide input to refined customer connection standards or intelligent grid solutions for improved network-wide hosting capacity.

4.3 Customer Connection Standards

Energy Queensland has many customers that connect at MV and HV level. These customers can be loads and/or generators. The load customers are principally industrial and mining sites while the generators are solar farms, sugar mills and biofuel generator sites.

Industrial and mining sites typically have large disturbing load such as numerous large variable speed motors and drives that impact on the power quality of the network and other customers. These sites and or feeders are monitored for PQ parameters.

Solar farm sites can impact on the power quality of the network and other customers. It is a connection requirement that all generator sites with convertor-based systems such as solar farms larger than 1.5MW are assessed to determine if a power quality analyser will be installed at the network connection point.

Rotary generator site connection requirements are reviewed as per the relevant connection standard.

Energy Queensland has an existing Connection Standard for customers connecting micro embedded generating units (MEGUs) to the network. It provides owners and proponents of MEGUs information about their rights and obligations for the connection (to) and interfacing with the Ergon Energy or Energex distribution networks. This standard has been developed in consultation with the MEGU industry and has evolved over the past five years, with the intention of cost-effectively facilitating the connection of MEGUs to the network, while also ensuring that individually and collectively installations do not cause a material degradation in the quality of supply to other network users nor adversely affect operation of the distribution network. An effective customer connection standard which specifies technical requirements and performance standards for MEGUs can reduce the requirement for network rectification works in areas where significant amounts of DER could otherwise cause quality of supply issues.

4.4 Intelligent Grid Solutions

As outlined in section 2.5, Energy Queensland's Customer Quality of Supply Strategy has been considered as part of an overall future grid strategy. The Future Grid Roadmap has been developed to provide a "no-regrets" roadmap to adapt and optimise the network to build an intelligent grid that leverages technology and data in new and innovative ways to support sustainable energy to provide reliable and valued services for the future. The Customer Quality of Supply Strategy complements the Future Grid Roadmap to maximise the benefit of any network investments required for quality of supply. This will ensure consistency with longer-term network strategy to achieve the outcomes of both the Future Grid Roadmap and the ENA/CSIRO's ENTR.

The Customer Quality of Supply Strategy proposes the development and implementation of new technologies to address potential quality of supply issues. These new technologies are predominantly proposed to manage steady state voltage and include devices such as LV regulators, LV Statcoms or switched capacitors and on-load tap changing distribution transformers. Although these technologies are proposed to efficiently address specific quality of supply issues, they will also support enabling connection of additional DER and future active network management initiatives.

4.5 Rectification Works

Although the implementation of the concepts detailed above should address the majority of customer quality of supply issues, it is anticipated that “traditional” network augmentation works will still be the most cost-effective solution for certain parts of the network. These augmentation works may include:

- Adjustment of distribution transformer tapping profiles
- Phase balancing on LV overhead feeders
- LV network upgrades, such as reconductoring overhead LV lines, or installation of an additional distribution transformer
- MV network upgrades, such as the installation of MV regulators or reconductoring of overhead MV lines.

5. Summary

This Customer Quality of Supply Strategy reviews the existing and emerging factors that must be managed to maintain an acceptable quality of supply along with customer and network safety into the future. These include the transition to a 230V standard; investigation and resolution of customer quality of supply enquiries, now dominated by solar PV, which continues to be installed in significant numbers and is not expected to slow in the near term; and the emerging DER technologies like BESS and EVs. While DER can pose risks to the network, the Future Grid Roadmap proposes an extensive body of work that not only mitigates these risks but cultivates new opportunities for customers and networks to collaborate so that safety and reliability are maintained while network expenditure is minimised.

Five key approaches for managing customer quality of supply have been reviewed. By first investing in improved monitoring and data analytics capabilities, network power quality issues can be identified proactively, investigated and analysed with minimal impact to customers. In addition, comprehensive connection standards reduce impacts associated with the connection of significant capacities of new generation and DER. Where customer quality of supply issues are identified, new intelligent grid technologies complement more traditional rectification options providing a diverse toolkit that can be drawn upon to resolve the limitation with the lowest cost. The Future Grid Roadmap then lays a path forward, to enable customers to offer alternative solutions that can further reduce network costs while maintaining safety, reliability and quality of supply.

Appendix 1. Definitions, Abbreviations and Acronyms

BESS	Battery Energy Storage System
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DER	Distributed Energy Resource
DSO	Distribution System Operator
ENA	Energy Networks Association
ENTR	Electricity Network Transformation Roadmap
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
HV	High Voltage (35kV – 230kV AC)
IS	Isolated System
LV	Low Voltage (50V – 1 000V AC)
MEGU	Micro Embedded Generating Units
MV	Medium Voltage (1kV – 35kV AC)
NER	National Electricity Rules
PQ	Power Quality (of the network)
PV	(Solar) Photovoltaic System
QoS	Quality of Supply (to a customer)
SCADA	Supervisory Control and Data Acquisition
ZS	Zone Substation