Appendix 5.8: Quality of supply strategy

Regulatory proposal for the ACT electricity distribution network 2019-24
January 2018

evoenergy

Table of contents

List of figures

List of tables

1. INTRODUCTION

This document defines the asset management strategies for the Quality of Supply associated with the Evoenergy Distribution electricity distribution network. Its purpose is to summarise the tasks and outline the key strategies Evoenergy is employing to meet its obligation to maintain the reliability, quality, safety and security of the distribution system as required by the ACT Utilities Electricity Distribution Supply Standards Code, National Electricity Rules and Australian Standards.

Evoenergy takes supply at 132kV from two connection points from the TransGrid 330kV network. The Evoenergy 132kV transmission network is reticulated to 12 zone substations and two switching stations. Evoenergy Also takes supply at 66kV from TransGrid to a single zone substation, Fyshwick.

The zone substations supply 11kV and 22kV distribution feeders which provide supply to approximately 192,000 customers at both low voltage (< 1kV) and high voltage (direct from 11kV). At all voltages in the Evoenergy network, the quality of supply is maintained to provide a safe and secure source of electricity.

Power quality is currently measured by the installation of mobile power quality analysers in various locations on the distribution network. Measurements are taken on both a proactive and reactive basis. Evoenergy has recently commenced installing permanent site power quality measuring devices that will aid this power quality data capture which will filter into other internal network support systems.

In addition, all new revenue meters installed must be Type 4 interval meters, which Evoenergy intends on utilising data obtained by these devices to identify issues before they become known to customers.

One of the key power quality challenges addressed in this strategic plan arises from the high penetration of domestic rooftop photovoltaic (PV) systems that are currently installed on approximately 19.4% of homes in the ACT.

The uptake of these systems has been increasing steadily over the past five years and there is currently, approximately 59.8MW of installed capacity.

Traditionally, distribution networks around the world have been designed to accommodate the flow of power in one direction from substations through to the customer. With the rise in distributed generation on the low voltage network, power flows can occur in both directions, leading to greater voltage regulation to be managed and operational issues to be addressed.

2. PURPOSE & STRUCTURE

2.1. Purpose

The purpose of this document is to describe the strategy adopted to meet customer requirements and regulatory obligations relating to power quality. The systems and processes it utilises provide valuable tools for holistic long term management of the electricity network and promote:

- Early detection of network problems;
- Planning information for substation upgrades, network upgrades and augmentations, as per the following Evoenergy Standards:
    - Distribution Network Augmentation
    - Distribution Network Planning & Expansion
- Enhanced performance monitoring to optimise network performance.

The strategies included in this document ensure that management of the quality of supply of the network will move to a more proactive approach and provide a more complete real time assessment of the range of quality of supply parameters.

This document forms part of Evoenergy's Asset Management System and should be considered in conjunction with other components of the system including Evoenergy's Service and Installation Rules (S&IR), Asset Specific Plans, and associated procedures/work practices.

The document describes the quality of supply strategy adopted to meet requirements during the period until the end of the next regulatory period ending in 2023/24. A periodic review of this document will occur at a frequency no greater than every five years.

2.2. Structure

To achieve this process, this quality of supply strategy is structured in the following way:

- Strategic Direction
- Background
- Current Environment
- Future Requirements

2.3. Definitions/Acronyms

TERM	DEFINITION
ADMS	Advanced Distribution Management System
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
AS or AS/NZS	Australian Standards or Australian/New Zealand Standards
Class A	This class of instrument is used where precise measurements are necessary, for example, for contractual applications that may require resolving disputes, verifying compliance with standards, etc.
CT	Current Transformer
EMF	Electromagnetic Fields
ENA	Energy Network Association
HV	High Voltage (Typically 11kV)
LV	Low Voltage (Typically 230/400V)
NER	National Electricity Rules
PV	Photovoltaic Cell
SCADA	Supervisory Control and Data Acquisition
S&IR	Evoenergy Service and Installation Rules
STPIS	Service Target Performance Incentive Scheme
TNSP	Transmission Network Service Provider
TransGrid	Owner and operator of the HV Transmission Network surrounding the ACT
UTR	Utilities Technical Regulator
VT	Voltage Transformer

2.4. References

2.4.1. Australian Standards

DOCUMENT NUMBER	TITLE
AS 2344	Limits of electromagnetic interference from overhead AC power lines and high voltage equipment installations in the frequency range 0.15 to 1000 MHz
AS/NZS 3000	Australia/New Zealand Wiring Rules
AS/NZS 3100	Approval and test specification, General requirements for electrical equipment
AS/NZS 4777.1	Grid connection of energy systems via inverters - Installation requirements
AS/NZS 4777.2	Grid connection of energy systems via inverters – Inverter requirements
AS/NZS 7000	Overhead Line Design – Detailed Procedures
AS 60038	Standard Voltages – Alternating (50Hz)
AS/NZS 61000.1.1	Electromagnetic Compatibility - (EMC) – General-Application and interpretation of fundamental definitions and terms.
AS/NZS 61000.2.2	Electromagnetic Compatibility - (EMC) – Environment-Compatibility levels for low-frequency conducted disturbances and signalling in public low-voltage power supply systems
AS/NZS 61000.3.2	Electromagnetic Compatibility - (EMC) Limits for harmonic current emissions (equipment input current ≤ 16 A per phase)
AS/NZS 61000.3.3	Electromagnetic Compatibility - (EMC) Limitation of voltage changes, voltage fluctuations and flicker in public low-voltage supply systems, for equipment with rated current = 16 A per phase and not subject to conditional connection.
AS/NZS 61000.3.4	Electromagnetic Compatibility - (EMC) Limitation of emission of harmonic current in low-voltage power supply systems for equipment with rated current greater than 75 A.
AS/NZS 61000.3.6	Electromagnetic Compatibility - (EMC) – Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems
AS/NZS 61000.3.12	Electromagnetic Compatibility - (EMC) Limits for harmonic current currents produced by equipment connected to public low-voltage systems with input current > 16A and ≤ 75A per phase.

AS/NZS 61000.3.13	Electromagnetic Compatibility - (EMC) – Assessment of emission limits for the connection of unbalanced installations to MV, HV and EHV power systems
AS 61000.3.100	Electromagnetic Compatibility - (EMC) Limits - Steady State voltage limits in public electricity systems
AS/NZS 61000.4.30	Electromagnetic Compatibility - Testing and measurement techniques - Power quality measurement methods
TR IEC 61000.3.7	Electromagnetic compatibility (EMC) Limits – Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems.

2.4.2. Evoenergy / ActewAGL Documents

DOCUMENT NUMBER	TITLE
ActewAGL Distribution Annual Planning Report 2016	ActewAGL Distribution Annual Planning Report 2016 Version 1 – December 2016
PR1115	Evoenergy Supply Voltage Standard for LV Systems
PR1169	Evoenergy Electric and Magnetic Field Measurements
PR1205	Evoenergy Voltage Profile Monitoring and Voltage Control
PR1314	Evoenergy Installing Loggers for Quality of Supply Surveys
SM1197	Distribution Network Augmentation Standard
SM1198	Distribution Network Planning & Expansion
SM1183	Evoenergy Electrical Data Manual
SM1138	Evoenergy Distribution Earthing Design and Construction Manual
SM1139	Evoenergy Distribution Overhead Line Design Manual
SM3201	Requirements for Connection of Embedded Generators up to 5MW to the Evoenergy Network
SM11144	Evoenergy Distribution Service and Installation Rules

2.4.3. Acts, Codes & Rules

DOCUMENT	TITLE
NER	National Electricity Rules - 2017
ACT Utilities Act 2014 (Technical Regulation) Section 65	Electricity Distribution Supply Standards Code
ENA EG-1-2006	Substation Earthing Guide
ENA DOC 025-2010 EG-0	Power System Earthing Guide – Part 1: Management Principles
ENA Doc 017-2008	ENA industry guideline for the inspection, assessment and maintenance of overhead power lines
ENA Doc 2016	EMF Management Handbook (January 2016)

3. STRATEGIC DIRECTION

3.1. Asset Management Strategy

This strategy is part of an overall strategic planning process that ensures that the corporate strategic objectives are operationalised within the business. This framework is characterised as shown in Figure 1.

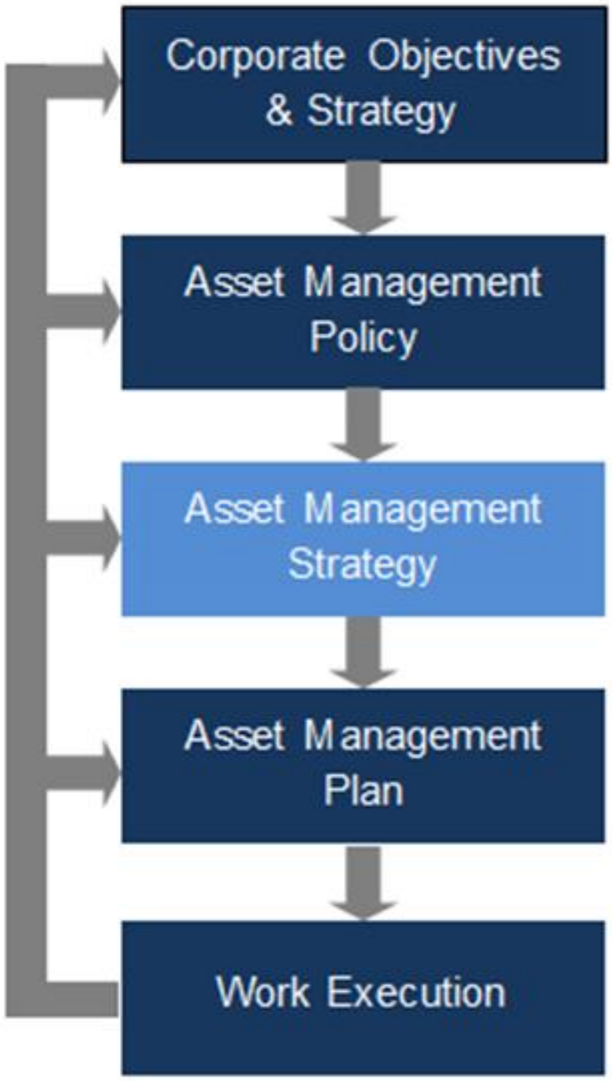

Figure 1. Evoenergy Organisational Strategic Process

The Asset Management Strategy is considered Evoenergy's second level of dissemination and definition of the organisation's Asset Management 'line of sight', which is initiated by our Asset Management Policy, and fully aligned with the overall Evoenergy Distribution Organisation Strategic Plan.

3.2. Quality of Supply Program Structure

Evoenergy Distribution's Quality of Supply Strategy framework is illustrated in Figure 2. It consists of foundation activities to further expand monitoring/reporting systems and measures established in previous years.

This framework supports investigations to identify non-compliant areas of the network with respect to statutory voltages and network standards leading to targeted rectification works in the short term.

This work will ultimately support long term adaptation of the low voltage network topology to fully accommodate the ongoing increase of solar PV penetration.

Figure 2. Quality of Supply Strategic Process

A key focus of the strategy is on minimising customer complaints and risk of damage to customer equipment from voltage outside of statutory limits with an emphasis on the impact of high solar PV penetration and the implementation of permanent power quality monitoring devices installed across the network.

3.3. Compatibility Levels

Electromagnetic compatibility (EMC) is concerned with the possible degradation of the performance of electrical and electronic equipment due to the disturbances present in the electromagnetic environment, in which the equipment operates.

The considerations for setting compatibility levels for each type of disturbance phenomena are:

- The compatibility level is the level of the disturbance that can be expected in the environment, allowing for a small probability (<5%) of it being exceeded.
- It is a disturbance level that can be maintained by implementing practicable limits on emissions.

- It is the level of disturbance from which, with a single margin, equipment operating in the relevant environment must have immunity.

3.4. Planning Levels

The planning level is locally specific, and adopted by Evoenergy for planning and operating its electricity distribution network. Planning levels are relevant, primarily to the medium, high and extremely high voltage networks. However, low frequency conducted disturbances pass in both directions between low voltage and the higher voltage networks.

The co-ordination of emission limits must take into account all voltage levels. Evoenergy endeavours to ensure all planning levels do not exceed the compatibility levels recommended by the relevant Australian Standards.

The use of planning levels is described in IEC/TR 61000.3.6 and IEC/TR 61000.3.7. The important points are:

- The planning level is a value adopted by the body responsible for planning and operating the power supply system in a particular area, and is used in setting emission limits for large loads and installations which are to be connected to the system.
- The planning level cannot be higher than the compatibility level. Generally it is lower by a margin which depends on factors such as the disturbance phenomenon involved, the structure and electrical characteristics of the supply network (provided it is adequately designed and maintained), the background levels of disturbance, and the possibility of resonance and load profiles.
- Although the planning level is related mainly to large equipment and installations, account must also be taken of the many other sources of disturbance, such as low-power equipment connected at low voltage. The over-riding objective is to ensure that the predicted level of disturbance does not exceed the compatibility level.

4. BACKGROUND

4.1. Power Quality

Power quality refers to the network's ability to provide customers with a stable sinusoidal waveform free of distortion, within voltage and frequency tolerances.

Power quality issues manifest themselves in voltage, current and frequency deviation, which result in premature failure, reduced service life or incorrect operation of customer and network equipment.

The NER Schedules 5.1a, 5.1 and 5.3 detail the applicable power quality design and operating criteria that must be met by Evoenergy. Evoenergy's Service and Installation Rules describe the applicable power quality design and operating criteria that must be met by our customers.

Electricity customers have ever-increasing expectations and are becoming less tolerant of power quality and reliability issues. Some modern appliances are not suited to events that occur on distribution networks due to their sensitivity and design.

At all voltages in Evoenergy's network, the quality of supply is maintained to provide a safe and secure source of electricity to our customers.

Power quality is measured by the installation of mobile power quality analysers in various locations on the distribution network. Measurements are taken on both a proactive and reactive basis.

Optimisation of network power quality enhances asset lifetimes due to reductions in operating stresses (e.g. lower transformer iron losses and resultant heating from harmonic voltage distortion).

Evoenergy has a proactive program to survey power quality across our distribution network. This program features the following:

- 70 randomly selected survey sites per year.
- For each site, measurements are taken at the customer point of supply.
- This provides Evoenergy with a network-wide picture of power quality through a structured randomised program.

This program is compliant with AS.61000.4.30 - Testing and measurement techniques - Power quality measurement methods.

Records indicate that since the 2006/07 financial year, in addition to routine proactive power quality monitoring, Evoenergy has investigated and resolved over 400 power quality enquiries from customers.

These enquiries have been steadily increasing since 2008/09. Figure 3 shows the number of power quality customer enquiries over the past ten years.

A direct correlation between the increase in solar PV systems connecting to the Evoenergy network and these power quality enquiries has been witnessed. Figure 4, in section 5.4.1, provides detail on the number of connected and approved solar PV systems connected to the Evoenergy network.

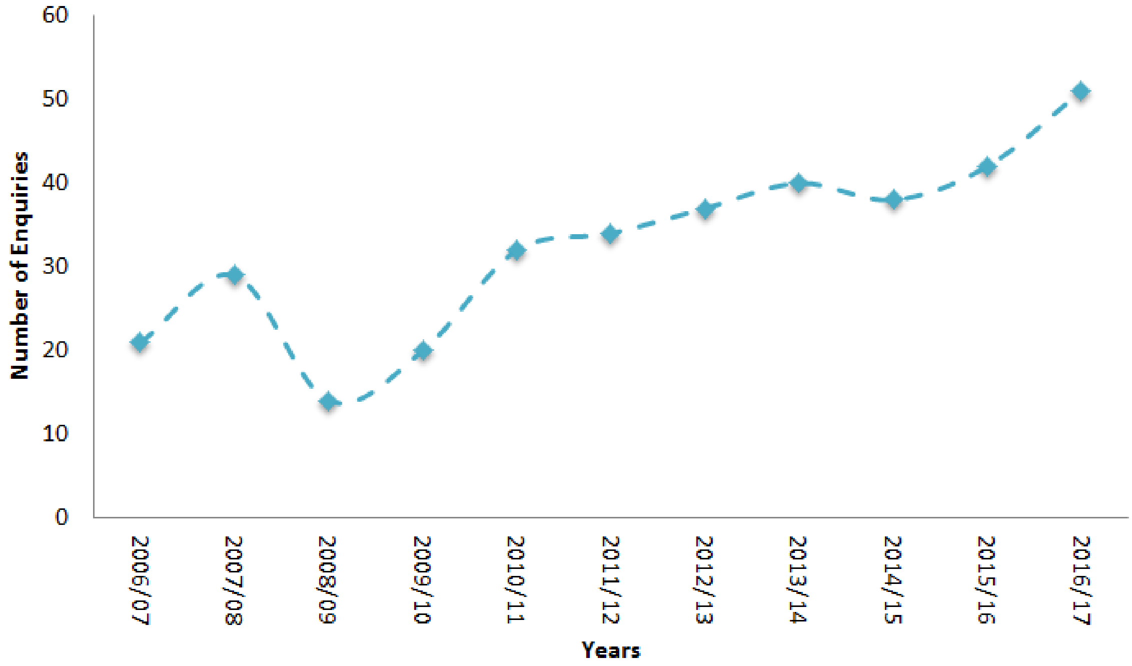

Figure 3. Power Quality Customer Enquiries by Year

4.2. Effects of Poor Power Quality

A network event related failure or damage to appliances may result in complaints or damage claims to the distributor. The effects of poor power quality can be varied. For domestic customer equipment, the inconvenience of poor power quality typically includes:

- Non-functioning cooking appliances.
- Air-conditioner or heat pump inoperable.
- The need for repeated resetting of electronic clocks.
- Damage to sensitive equipment such as personal computers and televisions.
- Degraded equipment life.
- Failure of equipment to operate correctly.

The effects of poor power quality for industrial customers are much more dramatic and costly. These include:

- Damage to equipment leading to expensive repairs/replacement.
- Incorrect equipment operation including unplanned tripping.
- Potential injury to personnel due to incorrect operation.
- Degraded equipment life.

- Excessive downtime.
- Loss of production.
- Degradation of product quality and excessive wastage.

Such events can result in a range of outcomes including:

- Lodgement of claims for damage and costs incurred with the distributor.
- Legal action in particular when injury or significant financial loss is incurred.
- Lodgement of formal complaints with respective ombudsmen or local members of Parliament.
- Adverse publicity for the Distributor.

4.3. Regulatory Requirements

The Utilities (Technical Regulation) Act 2014 that governs all utilities operating in the ACT, states in Section 3.3 (Enforcement of technical codes) that a regulated utility commits an offence if,

- A technical code applies to the regulated utility.
- The regulated utility fails to comply with a requirement of the technical code.
- The regulated utility is negligent about whether the technical code is complied with.

Statutory obligations regarding power quality arise through provisions of the technical code contained in the Utilities Electricity Distribution Supply Standards Code (The Code), The National Electricity Law, and consequently, the National Electricity Rules.

The regulatory obligations for power quality outlined to be monitored and analysed in The Code are:

- Steady-State Voltage
- Rapid Fluctuations in Supply Voltage (Flicker)
- Voltage Dips
- Switching Transients
- Voltage difference between Neutral and Earth
- Earth Potential Rise
- Voltage Unbalance
- Direct Current Component
- Harmonic Content
- Electromagnetic Fields
- Inductive Interference

These parameters are investigated by the use of a mobile power quality analyser at the point of connection for a minimum period of seven consecutive days. The measurements stored in the power quality analyser are then analysed by Evoenergy technical staff to gain an insight to identify areas of concern and implement remediation activities to repair non-compliant installations.

Although Power Factor management is not included under the obligations of The Code, Evoenergy Distribution undertakes monitoring of power factor as part of the ongoing program of proactive and reactive monitoring of the quality of supply performance of the network.

Evoenergy Distribution is monitored for regulatory compliance by the Technical Regulator using the legislative framework described above. Another legislative obligation is to comply with the utility licence annual report conducted by the ACT Independent Competition and Regulatory Commission (ICRC).

4.4. Customer Requirements

Evoenergy is contacted by customers whenever they experience equipment failure, reduced equipment service life or incorrect operation of equipment potentially as a result of inappropriate power quality. All such claims are evaluated by Evoenergy in order to assess their validity. This is the reactive quality of supply response process.

Customers expect a reliable and high quality power supply due to their lifestyle and increasing reliance on appliances; particularly electronic appliances. The sensitivity of many of these modern appliances is such that they are unable to continue satisfactory operation during infrequent power quality events that can occur on the distribution network.

The growing presence of PV on the distribution network has resulted in more reported instances of power quality related issues. Customers are better informed than in the past as relevant information such as the Electricity Distribution Code, Connection Contracts, Australian Standards, legislation etc. are readily available on the Internet.

4.5. Customer Enquiries

Evoenergy has received few substantiated quality of supply customer enquiries over the period from 2006 to 2016. Those that have been received have typically been in relation to voltage levels. Common resolution for typical complaints includes:

- Distribution transformer tap change
- Load balance on low voltage (LV) network
- Alteration of a customer’s phase connection
- Rectification of loose service cable/meter connections

There have also been some complaints regarding voltage harmonics and flicker. The investigation of these types of complaints includes the installation of a mobile power quality analyser for a specified time period at the customer’s point of connection to establish compliance status and, if necessary, identify the cause.

5. CURRENT ENVIRONMENT

5.1. Obligations

Schedule 5.1 of the NER lists the Network System Standards that are to be achieved by Network Service Providers (NSPs). Evoenergy's network planning strategy complies with these reliability and performance requirements when considering network developments.

These include:

- Magnitude of Power Frequency Voltage
- Frequency Variations
- Voltage Fluctuations
- Voltage Harmonics or Voltage Notching Distortion
- Voltage Unbalance
- Stability

Evoenergy's Distribution Network Planning and Expansion policy is the main document describing its planning policy. Evoenergy's planning process is an annual process and covers a minimum forward planning period of ten years.

The process commences with a comprehensive analysis of all indicators and trends to forecast the future load on the network. A detailed analysis of the network is then carried out to identify performance and capability shortcomings.

5.2. Power Quality Parameters

Evoenergy's proactive and reactive surveys, combined with the intended permanent site power quality devices will monitor all parameters as set out in The Code, NER and AS/NZS 61000 standards series.

5.2.1 Steady State Voltage

Voltage levels at customers' premises must be supplied and maintained within regulation limits to ensure correct operation of appliances and safety to equipment and personnel.

Voltage levels on the 132 kV bus at Canberra and Williamsdale bulk supply substations, is controlled by TransGrid via its 330/132 kV interconnecting transformers' on-load tap changers (OLTCs) and 132 kV capacitor banks. Similarly the 66 kV bus voltage, at Queanbeyan bulk supply substation is controlled by TransGrid.

The 11kV bus voltage at each zone substation is maintained by the voltage-regulating relay which controls the tap position of the 132/11kV transformers. In order to maintain the voltage within limits along the 11 kV feeders, the bus voltage is varied according to network conditions (loading, incoming voltage, feeder voltage drops etc.).

Evoenergy has installed Transmission Network Service Provider (TNSP) metering on the 11 kV group circuit breakers at all 132/11 kV zone substations. These meters provide accurate voltage measurements and other power quality information to the Advanced Distribution Management System (ADMS) in real time.

Evoenergy monitors steady state voltage levels and responds to customer complaints when received. Evoenergy shall use the implementation of the ADMS and the application of smart metering technology to further ensure compliance of steady state voltage levels.

The ADMS is undergoing an upgrade project which will see increased functionality such as power quality modelling, load flow calculations, volt-var optimisation and additional network study capabilities. The ADMS upgrade project is scheduled to be completed in 2019.

Steady state phase-neutral low voltage at the customer's point of supply is measured to ensure the V1%, V99% and V50%, (phase-to-neutral and phase-to-phase) as per AS/NZS 61000.3.100.

Table 1. Voltage Tolerance Limits

Voltage Boundary	AS 600038	AS 61000.3.100
Nominal Voltage	230 Volts	230 Volts
Upper Limit	+10%	+10%
Lower Limit	-6%	-6%
$V_{99\%}$ / V_{MAX}	253 Volts	253 Volts
$V_{1\%}$ / V_{MAX}	216 Volts	216 Volts
$V_{50\%}$ +	244 Volts	244 Volts
$V_{50\%}$ -	225 Volts	225 Volts
Utilisation Limit (+10% / -11%)	-	424 Volts (Phase-to-Phase Maximum) 253 Volts (Phase-to-Neutral Maximum)
	-	392 Volts (Phase-to-Phase Minimum) 204 Volts (Phase-to-Neutral Minimum)

5.2.1.1 Strategies to Address Steady State Voltage Variation

Evoenergy's quality of supply strategy ensures compliance with the standard voltage levels outlined in AS 60038 - Standard Voltages, as mandated by The Code. Evoenergy shall undertake to deliver on the following key strategic objectives:

- **Transmission Voltages (132/66kV)**

Undertake investigation with stakeholders, UTR, AEMO and TransGrid to identify means to maintain the transmission voltage within the required limits.

- **Distribution Voltages (11/22kV)**
    - Utilise the ADMS load flow functionality to provide real-time and calculated HV voltages across the network.
    - Continue to update all applicable distribution documentation to reflect revised voltage levels.

- **Low Voltage Network (230/400V)**
  - Utilise mobile power quality analysers that adhere to AS 61000.4.30 and are classified as “Class A” measurement devices to capture instances of steady state variations in the network.
  - Implement a revised proactive quality of supply survey program that enables Evoenergy to further classify the network’s steady state voltage compliance. The randomised program will involve monitoring a minimum of 70 sites per year.
  - Implement a revised reactive quality of supply survey process that enables Evoenergy to quickly respond to steady state voltage complaints and record the outcomes and information generated from the investigation of these complaints.
  - Use the revised supply voltage procedure when setting unloaded distribution transformers tap settings.
  - Utilise the ADMS load flow functionality to provide calculated LV voltages across the network. This information will assist Evoenergy in classifying overall network steady state voltage compliance.
  - Deliver high security 3G/4G wireless communication Access Point Network (APN) to smart meter power quality endpoints and integrate power quality data to the ADMS.
  - Continue to update all applicable low voltage documentation to reflect revised operating voltages and provide information to the wider business.

5.2.2 Rapid Fluctuations in Supply Voltage (Flicker)

Voltage fluctuations are defined as repetitive or random variations in the magnitude of the supply voltage. The magnitudes of these variations do not usually exceed 10 per cent of the nominal supply voltage, however small magnitude changes occurring at certain frequencies can give rise to an effect known as flicker.

In normal circumstances, the value of rapid voltage changes is limited to 3% of the nominal supply voltage. However step voltage changes exceeding 3% can occur infrequently on the distribution network. Flicker may cause spurious tripping of relays, interference with communications equipment, and may trip electronic equipment. Flicker is usually customer-generated due to the following:

- Frequent starting of induction motors – mainly the direct on line starting of induction motors.
- Electric welders.
- Arc furnaces.

Evoenergy responds to a customer report of flicker by installing a mobile power quality analyser. Evoenergy advises the customer if the flicker is due to their installation, or rectifies the fault if it is caused by Evoenergy’s equipment.

Evoenergy shall design, maintain and operate its network to ensure voltage fluctuations do not become excessive.

Compatibility levels shall be as per Table 2 for LV and MV systems.

Table 2. Flicker – Compatibility Levels Criteria

Compatibility Levels for Flicker in LV Systems	
P_{ST}	1.0
P_{LT}	0.8

Notes to Table 2:

1. Compatibility levels are not defined for MV, HV and EHV systems in the Australian Standards.
2. P_{st} refers to "short term severity level" and is determined for a 10-minute period.
3. P_{lt} refers to "long time severity level" and is calculated for a two-hour period. It is derived from the values of P_{st} for 12 consectutive10-minute periods.

These are the reference values for coordinating the emission and immunity of equipment which is part of, or supplied by, a supply system in order to ensure the EMC in the whole distribution network.

Planning levels shall be as per Table 3 for MV and HV systems.

Table 3. Flicker – Planning Levels Criteria

Planning Levels for Flicker in MV, HV & EHV Systems		
	MV	HV / EHV
P_{ST}	0.9	0.8
P_{LT}	0.7	0.6

Evoenergy requires voltage fluctuations and flicker in LV systems not to exceed limits in AS61000.3.3 and AS61000.3.5 as appropriate. Customer motor starting limitations are enforced by evaluation of load applications as part of the Customer Application Process.

Voltage fluctuations caused by equipment not directly connected to the Evoenergy network shall be controlled by connection agreement between Evoenergy and TransGrid.

5.2.2.1 Strategy to Deal with Rapid Fluctuations in Supply Voltage (Flicker)

Evoenergy's quality of supply strategy complies with the levels of Flicker outlined in AS/NZS 61000 Electromagnetic Compatibility - General as mandated by The Code.

Evoenergy shall undertake to deliver on the following key strategic objectives:

- Utilise mobile power quality analysers that adhere to AS 61000.4.30 and are classified as Class A measurement devices to capture instances of flicker in the network.
- Respond to customer complaints on a case by case basis;
- Analyse results from all proactive quality of supply surveys to detect signs of flicker and initiate rectification actions where necessary.
- Direct customers to take corrective actions if identified flicker is due to their installation

5.2.3 Voltage Dips

A voltage dip is a short duration reduction in supply voltage to between 10% and 90% of the steady state supply voltage for less than one minute, but generally lasting less than one second.

Voltage dips are typically caused by events such as lightning or faults on adjacent feeders, or are generated by equipment located within customers' premises (e.g. induction motor starting).

Dips caused by faults on adjacent feeders can propagate throughout the network, affecting customers' supply voltage on all feeders at the zone substation. Although only customers on the faulted feeder experience an interruption, many experience the reflected voltage sags generated by the fault.

Evoenergy monitors voltage dips as part of its power quality monitoring program. Evoenergy uses its SCADA system and protection records to analyse events and uses its mobile power quality analysers to assist in the analysis and rectification of voltage dips.

Evoenergy shall use the implementation of permanent power quality monitors, numerical protection devices and the ADMS to further reduce the overall number of voltage dips on the network.

Evoenergy proposes to review fault switching and investigate the use of auto-reclosers, sectionalisers and fault passage indication devices to reduce the impact of voltage dips.

Table 4. Voltage Dip – Technical Criteria Voltage Tolerances

Dips Down to % Nominal Voltage	Max No. of Dips per Year (per point of supply) Urban	Max No. of Dips per Year (per point of supply) Rural
< 30	2	6
30 – 50	20	40
50 – 70	20	40
70 – 80	25	50
80 – 90	200	300

5.2.3.1 Strategy for Dealing with Voltage Dips

Evoenergy will continue to ensure that the number of voltage dips mandated by The Code is not exceeded. Evoenergy shall undertake to deliver on the following key strategic objectives:

- Utilise mobile power quality analysers that adhere to AS 61000.4.30 and are classified as Class A measurement devices to capture instances of voltage dips in the network.
- Analyse results from all proactive and reactive Quality of supply surveys for instances of voltage dips and undertake rectification actions where necessary.

- Continue implementing numerical protection relays and fast current limiting fuses, as well as fault current limiting neutral earthing transformers to reduce the magnitude of voltage dips on the network.
- Utilise the ADMS to assist with accurately locating fault locations.
- Identify areas in the network that are likely to experience voltage dips through simulations undertaken on the ADMS.
- Continue to review fault switching processes by investigating the use of auto-reclosers sectionalisers and fault passage indication devices to reduce fault switching.

5.2.4 Switching Voltage Transients

Switching transients are primarily associated with the operation of circuit breakers and are typically the consequence of the switched current being extinguished prior to the natural current zero value of the sinusoidal current waveform. This characteristic is termed as current chopping.

The chopping of the current results in transient voltages being generated which enter and travel through the interconnected network. Switching transients can also be generated by the switching of lumped capacitances (e.g. capacitor banks).

Switching transients are typically high frequency, short duration voltage conditions (mainly overvoltage conditions) which can result in damage to sensitive equipment.

Evoenergy shall manage switching transient voltages through switchgear procurement standards (i.e. utilising switching equipment that has small chopping current characteristics) and asset specific maintenance regimes, and routine maintenance programs designed to avoid excessive switch contact arcing.

The Code specifies that the overvoltage due to switching transients be limited to a maximum of two (2) times nominal supply voltage.

5.2.4.1 Strategy for Dealing with Switching Voltages Transients

Evoenergy shall undertake to deliver on the following key strategic objectives to ensure switching transient voltages do not exceed the limits specified by The Code:

- Utilise mobile power quality analysers that adhere to AS 61000.4.30 and are classified as Class A measurement devices to capture instances of transients in the network.
- Continue to utilise switching equipment that has small chopping current characteristics and maintain Evoenergy switchgear procurement standards;
- Continue routine maintenance programs to avoid excessive switch contact arcing;

5.2.5 Voltage Difference between Neutral to Earth

Although neutral conductors are nominally near earth voltage, minor voltage differences will occur between neutral and earth. The voltage differences may be steady state, temporary or transient, or combinations of these components.

Voltage differences between neutral and earth can present the risk of damage to electrical equipment at customers' premises as well as a risk of electric shock and fire. Typically voltage differences can be caused by such things as:

- Inadequate earthing (high earth resistance or open circuit earth) at substations.
- Inadequate bonding of earth and neutral in Multiple Earth Neutral (MEN) systems.

Evoenergy adheres to the relevant distribution substation earthing requirements and advises customers of correct earthing practices. Evoenergy includes neutral to earth monitoring as part of its power quality monitoring program to assist with classifying neutral to earth voltage non-compliance.

Table 5. Voltage Difference between Neutral to Earth Limits

Voltage Difference between Neutral to earth
< 10 Volts (5 minute average at the point of supply)

5.2.5.1 Strategy for Dealing with Voltage Difference between Neutral to Earth

Evoenergy will continue to take all reasonable steps to ensure that the voltage differences between neutral and earth is limited to the value specified in The Code. Evoenergy shall undertake to deliver on the following key strategic objectives:

- Utilise mobile power quality analysers that adhere to AS 61000.4.30 and are classified as "Class A" devices to record the Voltage Difference between neutral and earth as part of the updated proactive and reactive quality of supply survey processes.
- Observe and adhere to the substation earthing requirements set out in the ENA EG-0 Power System Earthing Guide Part 1: Management Principles.
- Measure all substation-earthing systems for compliance during substation commissioning and as part of regular, programmed maintenance activities.
- Require customers to use the MEN method of earthing as prescribed in AS 3000 and Evoenergy Service and Installations Rules.
- Review and update Evoenergy's fault loop impedance testing procedure for neutral integrity testing.
- Investigate incidences of tingles or shocks.
- Utilisation of devices to test network integrity and fault loop impedance.

5.2.6 Earth Potential Rise

Earth potential rise refers to the localised increase in the voltage of an object that should remain at earth potential, and is typically caused by a fault current passing through an earth connection that is inadequate for the magnitude of the fault current. This can be due to:

- Inadequate sizing of the earth conductor relative to the maximum fault current.
- High impedance between the earth conductor and the mass of earth (true earth).

Under such conditions the passage of the fault current through the inadequate earth connection will result in a voltage increase on the earth connection for the duration of the fault. This condition can present risk of electric shock to a person who may be standing on “true earth” but is in contact with the inadequately earthed device. It can also result in damage to sensitive equipment.

Evoenergy complies with earth potential rise requirements by basing its network designs on reference publications. Evoenergy’s system is designed to ensure that step and touch voltages arising from earth potential rise are within the allowable limits set out in Section 10 of Australian Standard AS/NZS 7000 – Overhead line design.

Evoenergy inspects the earth connections on its distribution system on a five-yearly program.

5.2.6.1 Strategy for Dealing with Earth Potential Rise

Evoenergy shall undertake to deliver on the following key strategic objectives to ensure that the step and touch voltages arising due to the earth potential rise are within the allowable limits as specified in AS 7000:

- Utilise Class A devices to record the Earth Potential Rise as part of the updated proactive and reactive quality of supply survey processes.
- Observe and adhere to the substation earthing requirements set out in the ENA documents, Power System Earthing Guide – Part 1: Management Principles, Substation Earthing Guide and the ENA industry guideline for the inspection, assessment and maintenance of overhead power lines
- Conform to the updated Evoenergy *Distribution Earthing Design and Construction Manual* when implementing network design.
- Implement a five-yearly program to visually inspect earth connections as part of the distribution substation inspection regime.
- Continue an earthing audit program where earth resistance measurements are performed on selected assets to ensure that step and touch voltages remain within the allowable limits.

5.2.7 Voltage Unbalance

Voltage unbalance is a condition in which the RMS values of the phase voltages and/or the phase angles between consecutive phases are not equal. It is measured as the ratio of negative to positive sequence voltage.

Voltage unbalance arises from customers drawing unequal loads on each phase, from differing numbers of customers being connected to each phase, and from differences in the impedances of each phase on the network. High levels of voltage unbalance can damage three phase equipment.

Evoenergy’s objective is to limit voltage unbalance to less than the compatibility levels for low voltage networks in AS/NZS 61000.2.2, and the indicative planning levels for medium and high voltage networks in TR IEC 61000.3.13, as shown in table 6.

Table 6. Compatibility Levels for Voltage Levels in LV and MV Systems

Maximum Negative Sequence Voltage (% of Nominal Voltage)
2%

Notes to Table 6:

1. Up to 3 % may occur in some areas where predominately single-phase loads are connected.
2. Compatibility levels are not defined for HV and EHV systems.

When notified that a customer's equipment is adversely affected by voltage unbalance Evoenergy will take reasonable steps within its power to:

- Investigate and test for the unbalance
- Require an affecting customer to rectify the situation
- Correct, where practicable, unbalance of the voltage at the customer's point of supply, where it is outside the limits set by the relevant Australian Standard.

Additionally, The Code specifies that in the voltage of electricity distributed through its electricity network does not exceed:

- 6% difference between the highest and lowest phase-to-neutral or phase-to-phase steady state voltage (five minute average) for the low voltage network.
- 3% difference between the highest and lowest phase-to-phase steady state voltage (five minute average) for the high voltage network.

Evoenergy manages voltage unbalance within the required limits through appropriate design practices and transformer procurement specifications. Evoenergy uses its mobile power quality analysers and quality of supply survey procedures to identify and rectify voltage unbalance. This is supported through the use of ADMS monitoring and calculations to ensure compliance.

As a Distribution Network Service Provider within the National Electricity Market, Evoenergy is bound by the National Electricity Rules.

5.2.7.1 Strategy for Dealing with Voltage Unbalance

Evoenergy will continue to ensure that the number of level of Voltage Unbalance mandated by The Code is not exceeded. Evoenergy shall undertake to deliver on the following key strategic objectives:

- Utilise advanced mobile power quality analysers that adhere to AS 61000.4.30 and are classified as Class A devices to capture voltage unbalance as part of the updated proactive and reactive quality of supply survey processes;
- Utilise the ADMS to identify points in the network which may be experiencing voltage unbalance based on the ADMS load flow estimation algorithm.
- Continuing to use appropriate design methodology whereby balanced network impedances are achieved through ensuring, as far as practicable,

that the same conductors are used in each phase and that they are appropriately configured and overhead transpositions are appropriate for the network conditions;

- Procurement and installation of transformers only with ganged three phase tap changers.

5.2.8 Direct Current (DC) Current Component

A direct current component in the neutral conductor has the effect of offsetting the sinusoidal waveform and can be caused by equipment that has different operating characteristics in each half of the voltage cycle.

A high DC component can cause damage to electronic devices and impact on the correct operation of protective devices. It can also lead to an increase in losses and result in heating within electrical and electronic equipment.

Limiting the direct currents in the neutral to acceptable limits is important because such current can cause corrosion of the network and a customer's earthing system, possibly leading to unsafe operating conditions. Customers with equipment that causes DC current flow may need to install isolation transformers and should seek advice accordingly.

The Code specifies that electricity distributed through its electricity network does not exceed a direct voltage component of the neutral conductor with respect to earth of more than plus, or minus, 10 Volts at the point of supply.

Evoenergy also ensures that customer's embedded generation inverters, connected to the Evoenergy network, adhere to the relevant standards and regulatory requirements. Evoenergy publishes on its website a document entitled "*Requirements for Connection of Embedded Generators up to 5 MW to the Evoenergy Distribution Network*".

This includes the requirement that inverters must comply with the requirements of the Australian Clean Energy Council (CEC) and Australian Standard AS/NZS 4777.

5.2.8.1 Strategy for Dealing with DC Current Component

To ensure that the DC component of current remains within the prescribed limits EVOENERGY shall undertake to deliver on the following key strategic objectives:

- Utilise mobile power quality analysers that adhere to AS 61000.4.30 and are classified as Class A devices to identify instances of high DC component as part of the updated proactive and reactive quality of supply survey processes.
- Continue to inform customers of their obligations, specifically that direct current emitted from lighting equipment and domestic appliances is required to be within values outlined in AS 3100.
- Actively participate in inter-organisational electrolysis working groups that monitor the effect of cathodic protection schemes on networks to maintain contemporary knowledge for the minimisation of their impact to acceptable levels.
- Take necessary steps to ensure equipment has adequate immunity to DC current.

- Review all Evoenergy embedded generation requirement documentation to ensure the DC component emitted from customer installations is kept at a minimum.
- Ensure customer inverters connected to its network comply with the appropriate Australian Standards and regulatory requirements as identified in the Evoenergy embedded generation requirements documentation.

5.2.9 Harmonic Distortion

Almost all electricity customers generate harmonic currents that are injected into and absorbed by the supplying network. Harmonic currents are non 50 Hz AC currents and are usually customer-generated by non-linear loads. Industrial equipment (e.g. arc welders), variable speed drives, uninterruptible power supplies, and office equipment, are all sources of harmonic currents. Table 6 shows the compatibility levels for harmonic content in low voltage networks.

Harmonic currents flowing in transformers cause an increase in the copper (resistive) losses and iron (magnetising) losses. This distortion can cause the supply voltage waveform to depart from sinusoidal in a repetitive manner and can affect the operation of computer equipment, create noise on radio and television receivers, and cause vibration in induction motors.

Evoenergy responds to customer requests to measure and analyse harmonic levels by using its mobile power quality analysers to undertake harmonic monitoring as part of its proactive power quality surveys.

Evoenergy is currently investigating the use of the ADMS to identify areas of the network where harmonic levels are outside regulation limits and explore the potential of real-time harmonic monitoring at zone substations

Table 7. Compatibility Levels for Individual Harmonic Voltages in LV Networks

Odd Harmonics, Non-Multiple of 3		Odd Harmonics, Multiple of 3		Even Harmonics	
Harmonic Order (h)	Harmonic Voltage (%)	Harmonic Order (h)	Harmonic Voltage (%)	Harmonic Order (h)	Harmonic Voltage (%)
5	6	3	5	2	2
7	5	9	1.5	4	1
11	3.2	15	0.4	6	0.5
13	3	21	0.3	8	0.5
$17 \le h \le 49$	2.27x(17/h)-0.27	$21 \le h \le 45$	0.2	$10 \le h \le 50$	2.27x(17/h)-0.27

Notes to Table 7:

1. Reproduced from AS/NZS 61000.2.2
2. The corresponding compatibility level for the total harmonic distortion is: THD = 8% (LV) and 3% (HV).

Evoenergy shall design, maintain and operate its network to ensure harmonic distortion is not excessive. Planning levels shall be HB264-2003 for HV, MV and LV systems. Compatibility levels shall be as per AS/NZS 61000.3.2.

For LV loads of greater than 16 Amps, and less than or equal to 75 Amps per phase, Evoenergy requires harmonic current emissions not exceed the limits in AS/MNZS 61000.3.12.

For loads of 75 Amps per phase or more, Evoenergy requires harmonic current emissions no to exceed the limits in AS/NZS 61000.3.4.

Capacitor bank design shall ensure that harmonic resonance is avoided, if necessary by the inclusion of detuning reactors.

5.2.9.1 Strategy for Dealing with Harmonic Distortion

Evoenergy shall undertake to deliver on the following key strategic objectives to ensure that the harmonics are within the allowable limits as specified in The Code and AS 61000:

- Utilise mobile power quality analysers that adhere to AS 61000.4.30 and are classified as Class A measurement devices as part of the updated proactive and reactive quality of supply survey processes.
- Utilise TNSP metering installed at Evoenergy zone substations (through Evoenergy SCADA system into the ADMS) to monitor harmonic levels.
- Continue to monitor harmonic measurement as part of the proactive quality of supply surveys of the distribution network.
- Inclusions of harmonic allocation consideration in large customer's (e.g. large scale solar photovoltaic and DC traction systems) connection agreements to ensure these installations do not impact the quality of supply to other customers. Site harmonic measurements pre, and post installation will be undertaken as part of the commissioning process.
- Continue to respond to customer complaints on a case by case basis according to the updated reactive quality of supply procedure.

5.2.10 Electromagnetic Fields (EMF)

Electromagnetic fields are a key design consideration for bare electrical conductors such as overhead lines and bus-bars, particularly those which operate at high voltage. For conductors with an earth shield, such as underground cables, the fields are encapsulated within the cable and do not present external hazards.

Electromagnetic fields incorporate both electric fields resulting from the voltage on conductors and also the magnetic fields generated by the current flowing in the conductors. Both phenomena result in a "grading" of the respective fields from the conductor to the nearest earth location.

In terms of voltage there will be a voltage "gradient" between the conductor and earth. In terms of current there will be a grading of the magnetic field (flux density) from the conductor to the earth.

Depending on the strength of these fields minute currents can be induced in the bodies of animals and humans. Research is inconclusive at present but there are concerns as to the health implications of exposure to electromagnetic fields.

As such there are strict guidelines for the management of electromagnetic fields incorporated into the design of overhead lines and high current equipment.

The Energy Networks Australia (ENA) Association has published an EMF Management Handbook (January 2016) which describes EMF's in detail and methods to mitigate magnetic fields.

Evoenergy follows these guidelines where practicable and complies with the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) Guidelines in the design of its network with respect to electromagnetic fields.

5.2.10.1 Strategy for Dealing with EMF

Evoenergy will continue to take all reasonable steps to ensure that the EMF generated by its network is kept within the limits prescribed by (ARPANSA) Guidelines. Evoenergy shall undertake to deliver on the following key strategic objectives:

- Continue with representation on the ENA Management Committee to retain access to the proceedings of the EMF Advisory Committee and stay updated on the issues, practices and recommendations to reduce EMF levels;
- Maintain a prudent avoidance practice as recommended by ESAA;
- Adhere to EVOENERGY documentation when identifying design reservation and easement requirements;
- Investigate EMF complaints on a case-by-case basis.

5.2.11 Inductive Interference

Inductive interference refers to the ability of the magnetic fields generated by current flowing in typically overhead line conductors, to cause interference with other electromagnetic radiation such as radio, television and communication signals.

Evoenergy shall continue to undertake routine maintenance programs to ensure all equipment is in good working condition, in particular all HV and LV overhead lines, to ensure that inductive interference is within the limits specified Section 5 of Australian Standard AS/NZS 2344 –Limits of electromagnetic interference from overhead AC power lines and high voltage equipment installations.

5.2.11.1 Strategy for Dealing with Inductive Interference

Evoenergy will continue to take all reasonable steps to ensure that inductive interference is within the allowable limits specified in AS/NZS 2344. Evoenergy shall undertake to deliver on the following key strategic objectives:

- Continue to undertake routine maintenance on all assets that may cause inductive interference, in particular all Overhead HV and LV lines
- Adhere to Evoenergy design practices and technical specifications when designing overhead sections of the network;
- Investigate any complaints related to inductive interference and involve the Australian Communications Authority where necessary;
- Address potential inductive interference at zone substations as part of Evoenergy Earth Grid refurbishment program.

5.2.12 Power Factor

Power factor relates to the relationship between real and reactive power. In an alternating current (AC) system the in-phase portions of voltage and current waveforms produce active or real power which is the capacity of the electricity system to perform work.

The out of phase portions of voltage and current waveforms produce reactive power. The combination of active and reactive power is termed apparent power. Where the power factor is low, the apparent power is comprised of a large proportion of reactive power. This directly relates to an excess of reactive power in the network.

Thus, a low or poor power factor will result in inefficiency due to high apparent power loading with a low real power delivery. This applies to individual customer installations and to the electricity network as a whole. A poor network power factor will result in poor network efficiency, loss and capacity of power transformers and overloading of circuits. This in turn, will drive premature capital expenditure on capacity related network infrastructure augmentations.

Evoenergy endeavours to manage power factor within its network. Management practices include appropriate line design and transformer design. In addition, Evoenergy shall design, maintain and operate its network to ensure power factor requirements for TransGrid connection agreements and the National Electricity Rules are met.

In general, a power factor between 0.96 lagging and unity at times of peak load is required, as measured at the bulk supply point. Evoenergy shall enforce the requirements of the Service and Installation Rules to ensure customers comply with the minimum power factor requirements between 0.9 lagging and unity.

Evoenergy has also initiated projects to look at reactive power support as the network load increases over the next 10 – 15 years, with the installation of capacitor banks at various locations.

Evoenergy monitors the power factor at its zone substations with the use of its TNSP metering data supplied to the ADMS to identify areas of the network that may be experiencing power factor issues.

Evoenergy also monitors power factor as part of its programmed proactive and reactive monitoring of the distribution network. Once identified, Evoenergy will liaise with the customer in order to bring power factor within the required limits.

Customers can gain significant benefits by improving the power factor at their premises. These benefits include reduced electricity costs, increased plant load capacity and utilisation, and better voltage regulation. Improvement of power factor is usually achieved by the installation of capacitors.

5.2.12.1 Strategy for Dealing with Power Factor

- Utilise mobile power quality analysers that adhere to AS 61000.4.30 and are classified as Class A measurement devices as part of the updated proactive and reactive quality of supply survey processes.
- Utilise TNSP metering installed at Evoenergy zone substations (through Evoenergy SCADA system into the ADMS) to monitor power factor.
- Continue to monitor power factor measurement as part of the proactive quality of supply surveys of the distribution network.

- Continue to enforce a minimum allowable power factor of 0.9 (lagging) at the customer premises.

5.2.13 Frequency

Frequency is a measure of the rate, in cycles per second (Hertz, Hz) at which the alternating voltage and current oscillate between peak forward and reverse values. The nominal frequency of electricity through the Evoenergy Distribution Network is 50 Hz.

Evoenergy does not control the frequency and cannot warrant that the frequency will comply with any standard. The frequency is maintained automatically by the generators, and provided that there is a balance between generation and load, the frequency remains stable at, or very close to 50 Hz.

The normal operating frequency band, defined by the NER is set to 49.85 Hz – 50.15 Hz. Frequency excursions outside these levels will occur from time to time and in rare events, the supply may be interrupted if the frequency deviates excessively.

Most customers' equipment will remain unaffected by frequency variations unless widespread supply interruptions occur because of excessive, sustained frequency variations on the electricity grid.

5.2.13.1 Strategy for Dealing with Frequency Excursions

- Utilise mobile power quality analysers that adhere to AS 61000.4.30 and are classified as Class A measurement devices as part of the updated proactive and reactive quality of supply survey processes.
- Utilise TNSP metering installed at Evoenergy zone substations (through Evoenergy SCADA system into the ADMS) to monitor power factor.
- Implementation of under frequency load shedding protective relays installed at Evoenergy zone substations to assist in any required network reconfigurations.

5.3 Issues & Challenges

Evoenergy faces a number of specific network challenges and opportunities as it seeks to balance customer service and cost due to the impact of embedded generation.

5.3.1 Embedded Generation

5.3.1.1 Growth Rates

The growth rate in embedded generation has continued despite changes to the feed in tariffs, and is continuing to challenge the performance of the Evoenergy Distribution network.

Domestic rooftop solar photovoltaic generation systems are currently installed on approximately 9.4% of homes in the ACT. These vary in size from 1kW to 10kW capacity, as shown in Figure 4.

The level of penetration is increasing steadily due to a number of reasons that include:

- Cost of PV systems is decreasing as more units are produced (reduced manufacturing costs) and more suppliers entering this market.
- Some developments (notably Denman Prospect Estate) have mandated that PV systems must be installed on all new detached dwellings to be constructed.
- The climate in the ACT is conducive to PV with long sunshine hours annually.
- Increased awareness of the public to climate change issues and the benefits of renewable energy.
- The ACT Government is promoting its 100% renewable energy target and encouraging the installation of PV systems.

Traditionally, distribution networks around the world were designed to accommodate voltage drop arising from the flow of power from the high voltage systems through to the low voltage system.

With the connection of embedded generation on the distribution network, particularly the large number of connections of rooftop solar PV to low voltage systems, in some areas power flows in the reverse direction from low voltage to high voltage have occurred at times of peak solar generation.

This reverse power flow is less predictable and leads to both voltage rise and voltage drop along the feeder network having to be managed to ensure voltage at customer terminals stays within statutory voltage limits.

There is emerging evidence that high embedded generation penetration is already causing voltage rise beyond the statutory limit of 230V +10% (253 volts phase to neutral) in particular parts of the network.

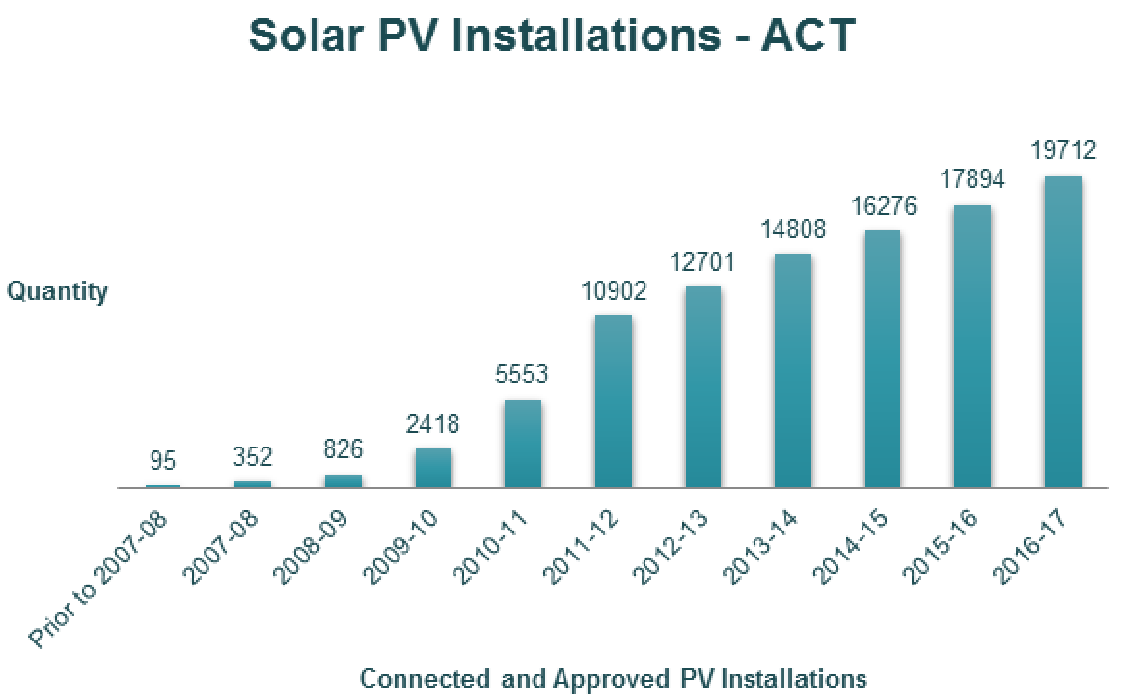

Figure 4. Solar PV Installations in the ACT

5.3.1.2 Non-Compliant Inverter Protection Settings

Evoenergy's Requirements for Connection of Embedded Generators – Class 1 systems (maximum single phase size of 5kW) state that the customer, through the installer, are required to ensure that the inverter has its overvoltage protection trip settings configured correctly (255V in early agreements and 260V in current agreements)

A large number of inverter's default overvoltage protection settings are between the 265 – 270V range. According to subjective reports few installers are altering these settings to align with the connection agreement; it is therefore highly likely that a large proportion of the installed inverters connecting to the Evoenergy network are not configured correctly.

This poses a risk of producing high voltages on the LV network in areas of high penetration of solar PV. This may increase the likelihood of LV circuit voltages being above the statutory voltage limits in some areas, damage to customer appliances and possibility of fire in extreme cases.

This issue needs to be addressed in the customer connection process. However, in practice, this will be a very difficult area to fix as it is not in the interest of suppliers, installers and customers, particularly if it means PV inverters are tripping more often.

Evoenergy believes high risk areas will need to be managed by a conventional network solution, at least in the short term, to lower voltage to reduce the risk of damage to customer installations.

5.3.2 Distribution Transformer Tap Profiles

Evoenergy selects distribution transformer taps based on no-load conditions. In the past, distribution transformers tap were selected to provide a no-load low voltage of 252 volts at the low voltage busbar in order to allow for voltage drop on the low voltage circuits.

Evoenergy policy has been amended to align with AS 60038 – *Standard Voltages.* The voltage measured at the low voltage busbar, under no-load conditions, must be as close as possible to the target values of 240 volts at a chamber substation and 245 volts at a distribution substation, as per PR1115.

The problem with this approach is that is does not consider light load scenarios that may produce high voltages that exceed statutory limits.

5.3.3 Phase Unbalance

Phase unbalance due to historically poor work practices connecting customers to the distribution network has been previously identified as an issue within Evoenergy. A substantial rebalancing program is required to remediate known areas of concern to ensure:

- Three phase voltages are maintained within NER requirements
- Single phase voltages on the low voltage network are maintained within statutory limits.
- Neutral currents are minimised

Some phase rebalancing work has been carried out on a reactive basis; however a program of work will need to be developed due to the large resourcing commitment needed to complete this work.

5.3.4 Neutral Integrity

Due to the impacts of ageing networks and environmental factors (e.g. corrosion), the integrity of Evoenergy’s neutral system can be impacted over time.

Evoenergy undertakes immediate rectification works once these faults are known, however there is potential for hazards to remain undetected. A monitoring system utilising customer smart meter’s is proposed to address this issue.

5.3.5 Extreme Voltages

Extreme voltages due to network events can increase the risk of an electrical fault at the customer’s premises that could lead to damage to sensitive equipment and property damage.

Power quality enquiries, particularly high voltage (LV), have been steadily increasing in numbers due to the penetration of rooftop solar PV systems. These areas are experiencing reverse power flow and voltage fluctuations that need to be managed.

Faults can also occur on the network, during storms with trees falling on power lines. These can also result in high voltage (11kV) being imposed on LV conductors. These events affect smaller numbers of customers but are more frequent in nature.

A monitoring system using customer’s smart meters is proposed to address this issue in areas deemed to have high risk due to either the age of the network, network condition or environmental factors.

5.4 Network Performance Tools

Evoenergy has traditionally utilised customer complaints to identify quality of supply issues. Moving forward, a preventative, and risk minimisation program utilising available and new technologies will be utilised to manage identified problems before they become known to customers or cause impact to the network.

5.4.1 TNSP Metering

Evoenergy has completed a capital works project to install TNSP metering at its zone substations to complete the necessary technical (metering) and associated regulatory works to perform the role of a TNSP, as defined in the National Electricity Rules (NER) chapter 7 and administered by the Australian Energy Market Operator (AEMO).

The TNSP metering interfaces with other metering and secondary systems equipment at Evoenergy's zone substations. These interfaces will be at defined connection points that comply with the NER.

The TNSP meters are installed in new dedicated metering panels, with the installation of new current transformers (CTs), voltage transformers (VTs), and new or upgraded communications equipment. This zone substation metering complies with Australian Standard AS/NZS 1284.13 – Electricity metering in-service compliance testing.

5.4.2 Smart Metering

The Power of Choice (PoC) rules to be implemented by the AEMC from 1 December 2017 will require all new and replacement meters to be Type 1-4 meters (smart meters).

Evoenergy is considering the utilisation of devices and communications facilities to enhance smart meters to offer the following functionality in addition to recording energy usage.

5.4.2.1 Outage Management

An enhanced smart meter can communicate with the ADMS when supply is lost, quickly indicating that a fault has occurred and its location. The operator will also be able to ascertain if the fault is on the network side or the customer's side of the meter.

5.4.2.2 Network Planning

Smart meters will provide accurate information of energy use and load data that can be used for network energy and demand forecasts. This will assist the future planning of low voltage networks in particular where standard values of load for customers are currently used, known as After Diversity Maximum Demand (ADMD) values.

5.4.2.3 Demand Management

Enhanced smart meters can be used to support demand side management by providing customers with details of their energy consumption and costs via web-portals, and providing customers with a range of energy plans to meet their individual needs.

5.4.2.4 Power Quality Monitoring

Enhanced smart meters can be used to record condition monitoring parameters that can be used for analysing network power quality to ensure compliance with standards. For example, Evoenergy currently investigates voltage complaints by installing temporary logging equipment at the customer's premises. Such information will potentially be remotely accessible in future from a smart meter.

5.4.3 Customer Enquiries

Evoenergy tracks the number of quality of supply issues by the amount of customer enquiries it receives. Over the past three years, the rate of quality of supply enquiries has been steadily increasing.

5.5 Risks

Most equipment is designed to operate at an optimum level at a particular voltage. When the voltage deviates from the “nominal” voltage, the performance is affected depending on the technology used. The impact of overvoltage and undervoltage on customer equipment is discussed in the following sections.

5.5.1 Overvoltage Impacts

Research on appliances subjected to elevated voltages has been conducted which shows that the majority of appliances are able to cope with short durations of over voltage, but for longer times, it has been concluded that the appliance lifetime will be significantly reduced.

Data presented in a CIRED International Conference paper in 2011 is shown in Figure 5 and Figure 6. It shows the impact of overvoltage magnitude and duration on 230V rated equipment under laboratory controlled testing. It shows that for sustained over-voltages in the 10-30 minute range there is relatively low failure rate (1-2%) between 115%-130%; however above 130% there is a significant and predictable increase in the number of failures.

As expected, short duration excursions are shown to have a higher voltage tolerance.

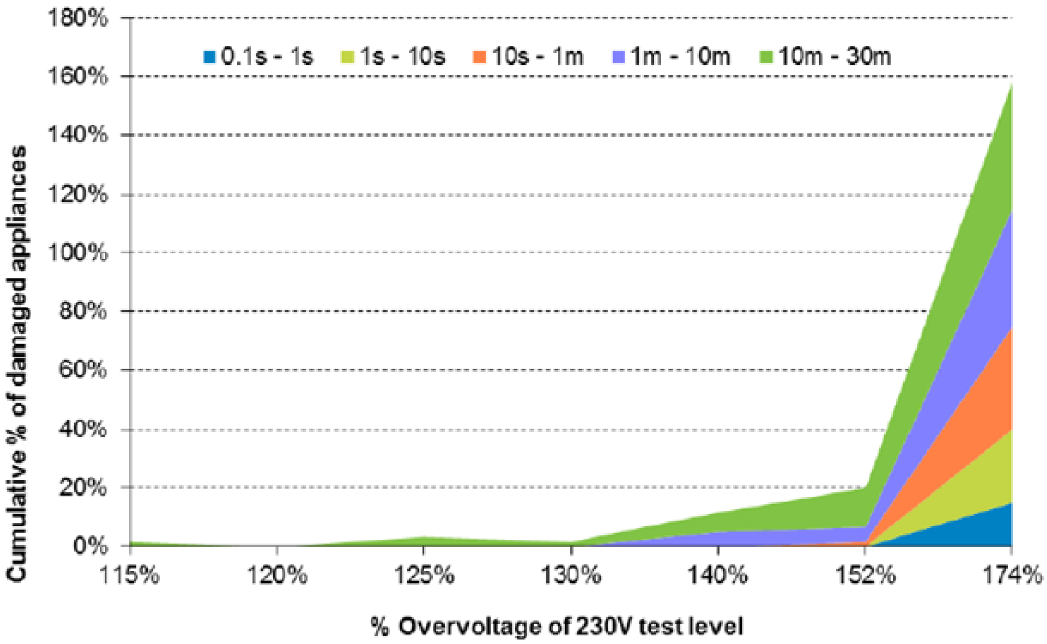

Figure 5. CIRED Paper – Overvoltage Appliance Testing (% Overload)

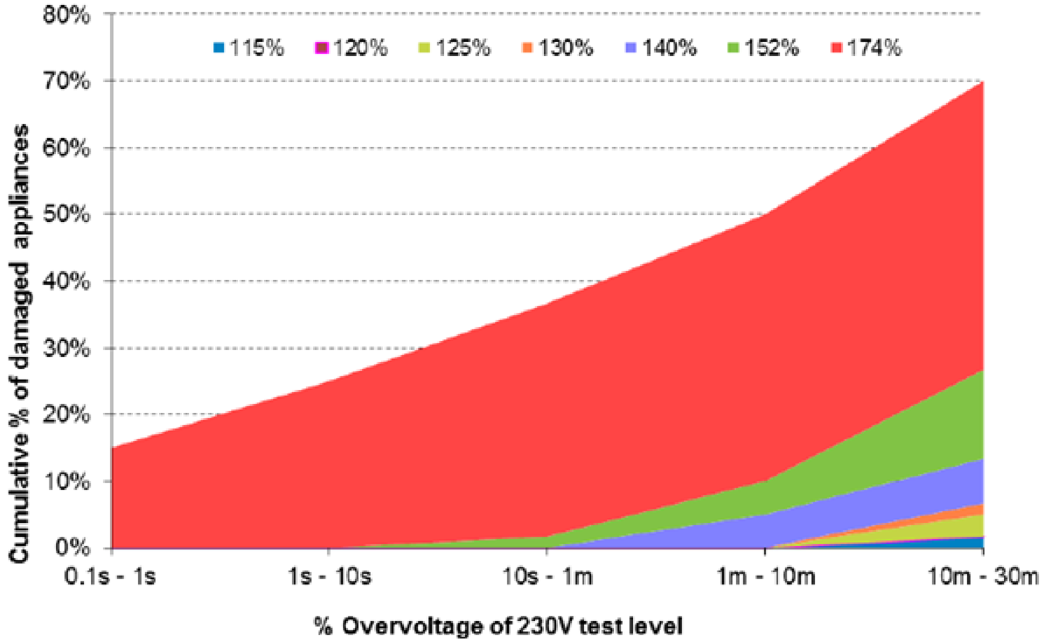

Figure 6. CIRED Paper – Overvoltage Appliance Testing (Duration)

5.5.2 Undervoltage Impacts

The effects of under voltage to Evoenergy's customers may include the following, resistive heating devices such as electric cooking appliances, water heaters, clothes dryers and hair dryers supplied at lower voltages will take longer to heat up.

Old electrical motors and pumps may overheat or malfunction if exposed to low voltages when starting or if heavily loaded. Overheating is caused by increased full load amps; a 10% drop in voltage will typically result in a 10% increase in current and an increase in temperature on the order of 10°C.

If the undervoltage, and associated temperature rise occurs while the motor is fully loaded, winding temperature may exceed design, which may halve insulation life for every 10°C rise in temperature. Reduced voltage also impacts on a motor's torque capability, increasing acceleration times, and creating the potential for insufficient starting torque or stalling under load.

5.5.3 Number of Areas Impacted by Voltage Issues

Evoenergy has 5,141 in-service distribution substations with 2,684 of these currently having solar PV connections located on their LV feeders, the majority on residential rooftops. Studies have shown that voltage related issues are more likely to occur, (on average) for customers connected towards the end of the LV circuits when PV generated power levels exceed approximately 20% of the transformer rating.

6. FUTURE REQUIREMENTS

6.1 Key Deliverables

In order to address the key drivers, issues and challenges, Evoenergy needs to better understand the performance of the low voltage network with respect to its obligations and the challenges it now faces.

This will identify areas of the network that require remediation and a range of projects to be implemented to mitigate the impact in the worst performing areas.

6.2 Challenges

6.2.1 Voltage Standard

The Australian Standard AS 60038-2000, “Standard Voltages”, published 23 February 2000, proposed a standard of 230 +10% / -6% volts for LV supply to align Australia with the IEC 60038:1983. Evoenergy has adopted these voltage standards.

6.2.2 New Technology

New technology is now becoming commercially available for managing voltage on the supply and customer side of the meter.

On the network side, this includes electronic devices that can automatically regulate the low voltage supply. Evoenergy has commenced trials with distribution padmount substation “on-load” tap changer in areas with high solar PV penetration.

On the customer side, this includes Australian Standard AS/NZS 4777 compliant solar PV inverts with reactive control capability and power export limiting devices.

The technology market will continue to be monitored for advances in voltage control technology and where economically and technically viable, these technologies will be introduced as a standard product.

6.3 Options Assessment

The program initiatives are based on the current regulatory requirement to maintain statutory voltages within the range of 230 volts (+10% / -6%) and will primarily address the worst areas emerging from growth of embedded generation on the Evoenergy network.

6.4 Program Initiatives

The initiatives outlined in this document have been developed to support electricity network remedial works and future power quality requirements.

Operational works include voltage regulation, distribution tap changer adjustment and rebalancing of connected loads across phases.

The capital works include a review of design practices; including increasing low voltage conductor sizing in identified areas and reducing the lengths of low voltage circuits.

These programs proposed takes a long term approach and seeks to optimise the distribution network voltage profile in conjunction with the current programs in place.

6.4.1 Distribution Substation Monitoring Project

The retrofit padmount transformer monitoring program of 20 trial sites using power quality meters to remotely read voltage and demand measurements, will take place in the 2017/18 financial year.

These units will be installed at identified sites on the low voltage network that are known to be experiencing power quality issues.

By installing these power quality devices, Evoenergy will be able to use the data captured to support analytic processes for resolving power quality issues to better prepare Evoenergy for the regulator-imposed Quality of Supply STPIS.

Forecast load requirements for input to strategic upgrades or enhancement of the distribution network. The installation of the devices in the distribution substations will also ensure regulatory compliance by Evoenergy for control and monitoring of the low voltage network for parameters such as, steady state voltage, sags and harmonics.

A further 150 units, per year are planned for installation during the 2019-2024 regulatory period.

6.4.2 Voltage Monitoring and Reporting

Due to the large number of sites involved in the Evoenergy Distribution network, the management of voltage presents some challenges. To address these challenges, a systematic approach is being implemented, as shown in Figure 7.

This involves:

- Establish data capture and reporting systems to identify problem areas.
- Establish objective measures and supporting systems for prioritising remedial works.
- Implement improvements from remediation programs.
- Measure results to improve the network model and remediation opportunities.
- Develop network models down to the low voltage network that allow problem areas to be predicted via the use of the ADMS

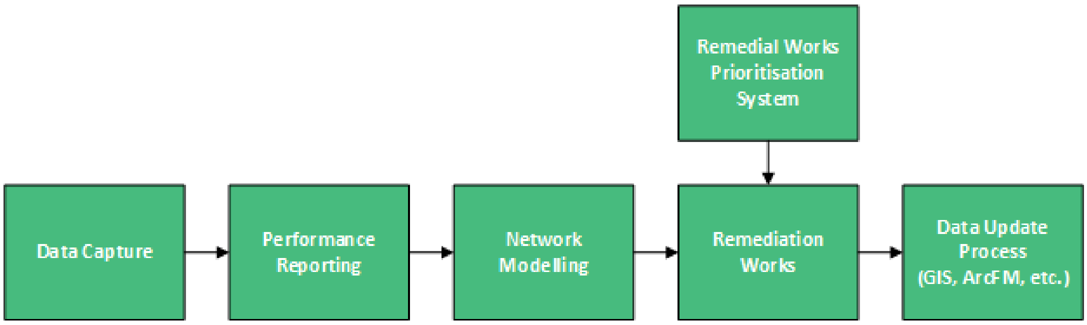

Figure 7. Voltage Management and Reporting Work Flow

6.4.3 Field Data Capture

This initiative supports the review of existing voltage management by addressing the lack of robust data on the low voltage network. This program will confirm substation details, installed equipment, transformer nameplate data, tap positions and settings.

As indicated in this document, the incorrect setting of distribution transformer tap settings may be contributing to the increasing number of customer enquires with regards to voltage issues.

A program to collect and record this data is proposed in the 2019-24 regulatory period, across a number of key stakeholders within Evoenergy, which will enhance the current distribution substation data capture program.

6.4.4 Voltage Investigations

The generalised variation of steady state voltage at the point of connection is shown, assuming a normal probability distribution in Figure 8.

The red curve shows the $V_{99\%}$ voltage distribution and possible remediation strategies to reduce customer initiated and network identified high voltage complaints.

Where the overvoltage level is at, or slightly above the upper voltage limit (253 Volts), this may be fixed by altering the zone substation LDC settings.

Where the overvoltage is above the upper voltage limit (255 Volts and above), this may be fixed by adjusting the tap setting at the distribution substation.

The green curve shows the $V_{1\%}$ voltage distribution and possible remediation strategies to reduce customer initiated and network identified low voltage complaints.

Where the undervoltage level is at, or slightly below the lower voltage limit (216 Volts), this may be fixed by altering the zone substation LDC settings.

Where the undervoltage is below the lower voltage limit (214 Volts or less), this may be fixed by adjusting the tap setting at the distribution substation.

Evoenergy's aim is to ensure that the $V_{50\%}$ voltage distribution is set between a minimum of 225 Volts and 244 Volts at the point of connection.

High and Low voltage issues need to be addressed as a matter of priority, as well as ensuring the overall voltage falls within the allowable 16% voltage range.

Data acquisition from monitoring equipment, modelling, network characteristics, solar PV penetration, inverter high voltage nuisance tripping complaints and to a lesser extent customer voltage complaints in general will be used to identify areas requiring remedial works.

Engineering guidelines are currently under development to assist this process as well as a remediation analysis and prioritising tool.

To address high solar PV areas a substation penetration threshold of around 30% will be targeted. It is acknowledged that growth in solar PV, over the regulatory period may significantly increase the number of distribution transformers with 30% penetration.

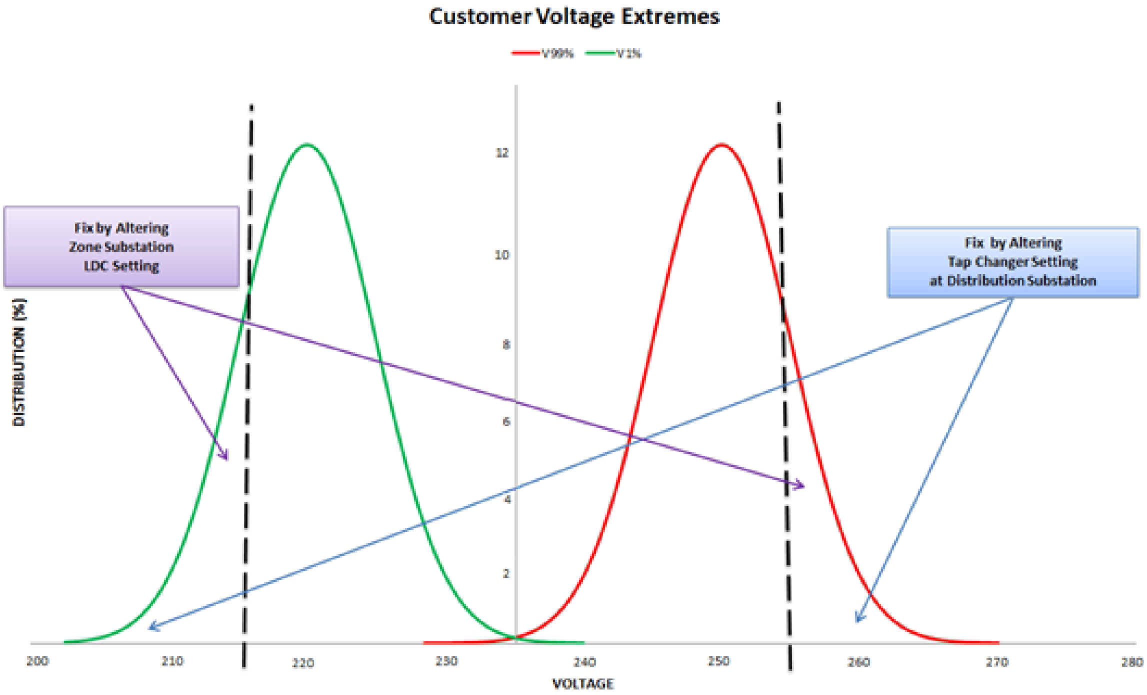

Figure 8. Distribution Transformer / Customer Voltage Variation

6.4.5 Network Solutions

6.4.5.1 Installation of Distribution Substation Monitoring Devices

A pilot project has been approved for the installation of permanent power quality monitors at twenty distribution substations. These will be installed in the 2017/18 financial year and will provide real time measurements to ADMS to further improve monitoring and modelling accuracy.

6.4.5.2 Low Voltage Distribution Network Upgrades

Two conventional network solutions are available to effectively address the voltage regulation and voltage rise issues on the LV network:

- Replacing smaller cross-sectional LV circuit mains and/or service conductors to customers.
- Reducing excessive lengths of LV circuit mains (those in excess of 400m) by installing additional distribution transformers points and reconfiguring LV open points.
- Exploring the installation of distribution on-load tap changers, Stat-Coms, and LV Regulators

These solutions work by reducing the impedance at the customer point of connection, but have the advantage of providing additional benefits for the network in terms of reliability, safety and capacity improvements.

6.4.5.3 Review of 11kV Voltage Regulation Settings

Evoenergy zone substation transformers have tap-changers installed in order to regulate the voltage on the 11kV outgoing feeders. Typically, the setting range for the regulating value is set to 100% with a sensitivity of 0.9 volts. This equates to 110V secondary, which reflected to the primary provides 11kV.

Evoenergy will review and investigate the 11kV voltage regulation settings from calculations obtained from the ADMS and a protection design review. A trial zone substation will be identified to implement these voltage regulation setting amendments to gauge their effectiveness in reducing high voltage customer complaints.

A review of the substation Line Drop Compensation (LDC) and distribution tap setting policy is underway and will be used as the basis for any future changes. This review will also include overlap with the distribution transformer tapping setting to ensure an effective solution is achieved.

6.4.5.4 Review of Distribution Transformer Tapping Settings

Evoenergy’s proactive power quality surveys indicate that V_1% readings are well above the statutory limits and there are no compliance issues with the 2016/17 survey sample. Evoenergy is already engaged in adjusting distribution transformer taps to correct for high voltage.

This tapping program needs to be well managed to ensure all customers supplied by targeted transformers receive acceptable voltage after transformer voltages are reduced. Where practical, a three point survey of voltage after the transformer tap adjustment will be carried out to ensure the voltage at the customers point of connection are within statutory limits.

Voltage improvement by distribution transformer tap adjustment will continue to be carried out as cases are identified, however this review will form part of the 11kV voltage regulation setting review.

6.4.5.5 Increased Proactive Monitoring Survey

Evoenergy’s current proactive power quality monitoring survey is carried out at a minimum of 70 sample sites, as per AS 61000.3.100.

In order better understanding of the distribution network, Evoenergy will increase its monitoring survey to provide significant coverage of the distribution. A proposed random sample size of 200 sites within three years should achieve this.

Areas that have been identified as having high PV penetration rates or other quality of supply risks will be targeted as a part with this increased proactive monitoring survey. Substations that have a penetration level of 30% will specifically be targeted.

It is acknowledged that growth rates in solar PV will steadily rise over the coming regulatory period, which will increase the number of distribution transformers with 30% penetration.

6.4.5.6 Low Voltage Customer Monitoring

This strategy aims to gain greater knowledge and insight into the voltage being experienced at the customer point of connection in targeted areas, to improve voltage management decision making. Initially, it is proposed that this scheme will target areas of the Evoenergy network that have been identified as having multiple issues.

This approach has the potential to provide a low cost solution to voltage monitoring across the network with minimal additional effort.

6.4.5.7 Low Voltage Distribution Conductors – Phase balancing

Phase unbalance needs to be reduced to meet NER requirements and also enable steady state voltage to be managed. This encompasses both load and solar PV inverter connections. Due to the greater number of customer service connections on 'A' and 'B' phase in LV overhead areas, randomly connected solar PV installations will also exhibit this bias.

Typically voltage unbalance will occur at times of peak solar PV generation in the middle of the day and at the times of peak residential loads in the evening when solar PV is not generating.

Currently customers connected to a phase with more generation are likely to exhibit a greater chance of high voltage outside steady state limits. Conversely, customers connected to a more heavily loaded phase when solar is off will exhibit a greater likelihood of under voltage outside steady state limits.

With phase unbalance, changing distribution transformer tap settings can fix a high voltage and make a low voltage worse or the converse.

By undertaking a phase balancing program, customer phase allocation is changed in order to more evenly distribute generation and loads across the three phases, which reduces the occurrence and magnitude of over and under voltages for customers.

The best network approach from current experience has been to rebalance a low voltage area by doing house counts per phase, considering the distance to the transformer by the method of moments and redesigning an area to put even numbers of houses on each phase. This is best done by a manual method to minimise phase changeovers. Reconnections are then carried out in the field to implement the redesign.

Additional benefits include:

- Improved LV circuit utilisation
- Improved distribution transformer utilisation and savings in upgrading costs
- Improved customer outcomes in terms of reduction in voltage complaints
- Reduction in neutral voltage problems and shock complaints
- Possible additional solar PV network capacity

6.4.5.8 Customer Voltage Controlled Solar PV with/without Battery Storage

This initiative would promote the requirements for future solar PV inverters to have the capability to control voltage so that voltage rise on the network is controlled by the ability of the inverters to absorb reactive power.

This could be achieved by inverters having a volt-VAr droop characteristic or being set to a fixed power factor, e.g. 0.9 lag.

Changes to Australian Standard AS/NZS 4777 have introduced requirements and recommendations for these functions. Evoenergy may also be able to leverage off this capability as an alternative to a network solution by offering a rebate to change out an old inverter for this new technology.

Further into the future, the possible take-up of battery inverter technology within customer installations may provide opportunities for network businesses to offer demand response arrangements that better manage network capacity and voltage constraints.

This will enable future network augmentations to be optimised and existing assets to be utilised fully.

6.4.5.9 Participation in Power Quality Benchmarking Programs

The University of Wollongong have been engaged by Evoenergy for a two year period to analyse the 2016/17 and 2017/18 supply monitoring data from Evoenergy's proactive power quality monitoring program to benchmark against industry standards.

The findings that the University of Wollongong provide will be reviewed and implemented where appropriate in the Evoenergy quality of supply strategy.

6.4.6 Summary

Some of the described initiatives are a continuation or expansion of existing programs, while others are new, being required to address the emerging issues.

These capital programs will be supported by operating initiatives that include Evoenergy initiated investigations addressing solar issues, rebalancing of the LV phase connections and resetting of distribution transformer taps.

Appendix A – Program Initiatives Plan

Action	Identified Period	Implementation Date By	Branch
Distribution Substation Monitoring Project	2017-18 Financial Year	June 2018	• Asset Strategy • Network Performance
Review of 11kV Voltage Regulation Settings	2017-18 Financial Year	June 2018	• Network Performance
Review of Distribution Transformer Tapping Settings	2017-18 Financial Year	June 2018	• Asset Strategy • Network Performance
Installation of Distribution Substation Monitoring Device	2018-2024	June 2024	• Asset Strategy • Network Performance • Works Delivery
Field Data Capture	2018-2024	June 2024	• Network Performance
Increased Proactive Monitoring Survey	2018-2024	June 2024	• Network Performance
Low Voltage Customer Monitoring	2018-2024	June 2024	• Network Performance
Low Voltage Distribution Network Upgrades	2018-2024	June 2024	• Asset Strategy • Customer Connections
Participation in Power Quality Benchmarking Programs	2018-2024 Regulatory Period	June 2024	• Network Performance
Low Voltage Distribution Conductors – Phase balancing	2019-2024 Regulatory Period	June 2024	• Network Performance
Customer Voltage Controlled Solar PV with/without Battery Storage	2019-2024 Regulatory Period	June 2024	• Asset Strategy • Network Performance