# APPENDIX 29

## Power quality strategic plan

Energex regulatory proposal – October 2014

# Energex

## Power Quality Strategic Plan

## 2015-20

### Asset Management Division

energex

positive energy

**Version control**

| Version | Date | Description |
|---|---|---|
| 1 | 25/09/2014 | Final for Regulatory Submission |
| | | |

Energex Limited (Energex) is a Queensland Government Owned Corporation that builds, owns, operates and maintains the electricity distribution network in the growing region of South East Queensland. Energex provides distribution services to almost 1.4 million domestic and business connections, delivering electricity to a population base of around 3.2 million people.

Energex's key focus is distributing safe, reliable and affordable electricity in a commercially balanced way that provides value for its customers, manages risk and builds a sustainable future.

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# 1 Introduction

This Strategic Plan addresses the Power Quality current obligations, environment, drivers and future requirements, focussing on voltage management on the low voltage network. The outcome is a number of capital and operational program initiatives that balance outcomes for the network and customers in alignment with Corporate and Asset Management Strategies.

One of the key power quality challenges addressed in this Strategic Plan arises from the high penetration of customer solar photovoltaic (PV) systems on the Energex network. Energex has experienced rapid growth in solar PV over the last five years with 261,500 connections at the end of June 2014. This equates to around one in four residential homes now having installed it, with a total capacity of 843 MW. This makes solar PV installed capacity equivalent to the fourth largest generator of electricity in Queensland and the highest per-capita capacity of rooftop solar worldwide.

The proliferation of solar PV is expected to continue in South East Queensland, albeit at a lower rate than the past three years, currently at around 3,000 connections per month. The challenge for Energex is to incorporate the evolving requirements of customers into business as usual activities. With current growth, connections are expected to reach around 420,000 by 2020. Beyond 2020, there is a high degree of uncertainty as to take up rates.

Traditionally, distribution networks around the world were designed to accommodate the flow of power in one direction from the substations through to the customer. However, with the rise in distributed generation on the LV network, power flows can now 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 Strategic Plan is to identify:

- The strategic objectives and operational requirements of the business over the next regulatory period;
- The existing and ongoing capability to manage voltage on the LV network;
- Any shortfalls between current capability and future requirements, considering the greater penetration of Solar PV; and
- The most cost effective way of delivering voltage management to meet future operational requirements.

This Strategic Plan is prepared in compliance with Energex's Corporate Strategy.

## 2.2 Structure

To achieve its purpose, the Strategic Plan is structured according to the following sections:

1) Strategic Direction – provides an overview of the strategic planning process and explains how the corporate strategic objectives are translated into operational initiatives and outcomes to be delivered by this Strategic Plan;
2) Current Environment – details the current operational capability of current SCADA and Automation services;
3) Future Requirements – specifies the core deliverables, changing environment, options and program initiatives
4) Governance & Review – sets out the governance arrangements associated with this Strategy Plan.

# 3 Strategic Direction

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 by the inter-linkages detailed in Figure 1.

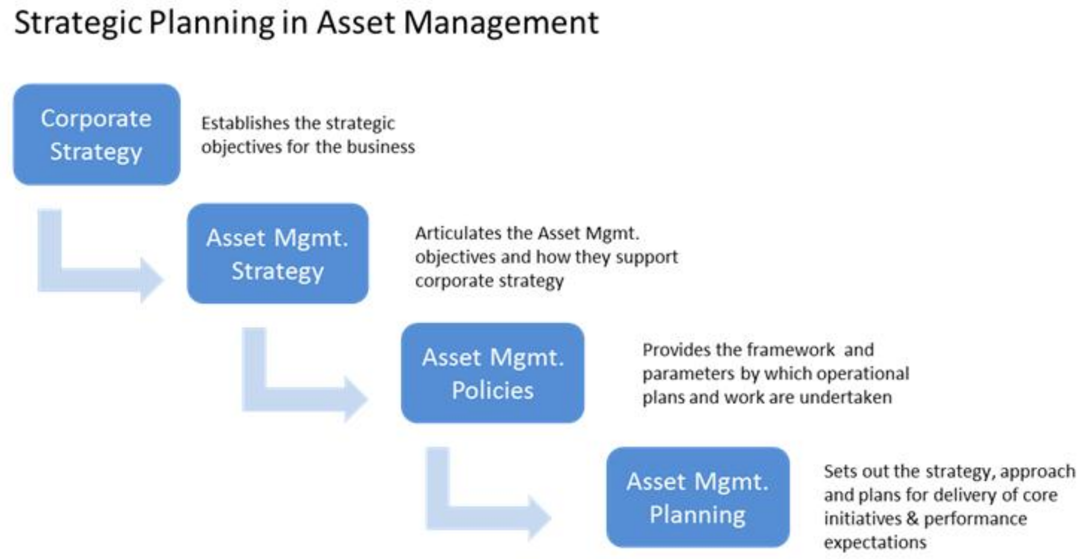

**Figure 1: Energex's Strategic Planning Process**

## 3.1 Network Asset Management Strategy

Energex’s network asset management strategy aims to achieve the following objectives:

- compliance with statutory obligations including safety, environment, and regulation and Energex Distribution Authority, policies and standards
- business outcomes achieved and customer and stakeholder expectations met including acceptable levels of network reliability
- investment principles and optimised asset investment plans that balance network risk, cost and performance (service) outcomes
- a focus on asset life cycle management including asset data and information and communication technology (ICT) initiatives (data adequacy and quality)
- modernisation of the network to meet required business and customer outcomes
- further development of Energex’s asset management system (practice).

Section 3.2 details how the Power Quality Strategic Plan directly contributes to these objectives.

## 3.2 Power Quality Program Strategy

Energex's 2015-20 Power Quality Strategy framework is characterised in Figure 2. It consists of foundation activities to further expand monitoring / reporting systems and measures established in 2010-15. This then 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 adaption of the LV network topology to fully accommodate the ongoing increase of solar PV penetration.

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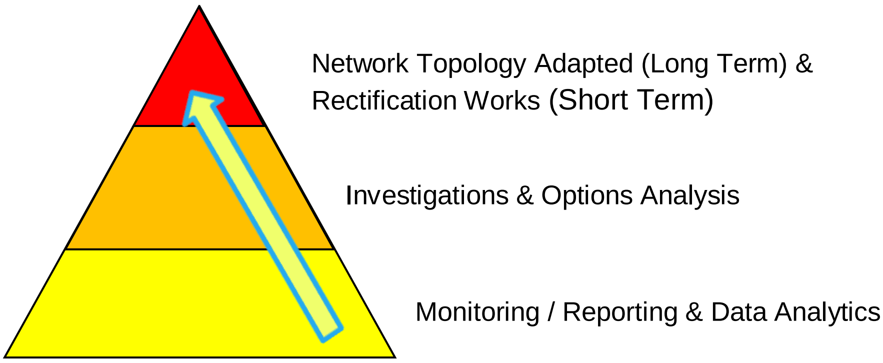

**Figure 2: Power Quality Strategy Hierarchy**

A key focus of the strategy is on minimising customer complaints and risks of damage to customer equipment from voltage outside statutory limits arising from the impact of high solar PV penetration. Although the program assumes the use of existing network building blocks, new technology may be substituted where it is technically proven and economically viable.

This strategy aligns to the Energex Network Asset Management Strategy in the following ways:

- compliance to statutory requirements and core obligations to manage voltage on the network
- expected business outcomes & fulfilment of stakeholder expectations by ensuring the LV network is 'fit for purpose' to accommodate changing customer energy usage patterns and increased levels of Solar PV penetration.
- balanced commercial outcomes by ensuring the investment in the LV network is optimised to address risk, cost and performance

The network risks being managed as part of this strategic plan will be assessed in accordance with the Network Risk Framework. Detailed network risk information will be incorporated in the specific project/program planning documentation.

# 4 Current Environment

## 4.1 Obligations

Schedule 5.1 of the NER lists a range of network performance requirements to be achieved by Network Service Providers (NSPs). Accordingly, Energex's planning policy takes these performance requirements into consideration when considering network developments.

Some of the requirements under the Rules are listed as follows:

- **Magnitude of Power Frequency Voltage:** During credible contingency events, supply voltages should not rise above the time dependent limits defined in Figure S5.1a.1 of the Rules. (For normal steady state conditions, a requirement of ± 6% for low voltage and ± 5% for high voltage of 22 kV or less is specified in the Electricity Regulations S13.);

- **Voltage Fluctuations:** A NSP must maintain voltage fluctuation (flicker) levels in accordance with the limits defined in Figure 1 of Australian Standard AS 2279.4:1991. Although a superseded standard, it is specifically referenced under a Derogation of the Rules (S9.37.12) applicable to Queensland;

- **Voltage Harmonic Distortion:** A NSP must use reasonable endeavours to design and operate its network to ensure that the effective harmonic distortion at any point in the network is less than the compatibility levels defined in Table 1 of Australian Standard AS/NZS 61000.3.6:2001; and

- **Voltage Unbalance:** A NSP has a responsibility to ensure that the average voltage unbalance measured at a connection point should not vary by more than the amount set out in Table S5.1a.1 of the Rules.

Energex's Supply and Planning Manual is the main document describing its planning policy with respect to power quality. This applies to all supply and distribution planning activities associated with the network. It describes strategies that customers can adopt to improve voltage quality, particularly with respect to the installation of equipment that has the potential to reduce power quality. It also notes that the 230 V,+10%,-6% standard associated with AS60038-2000 (standard voltages) is generally met by the requirements of the Queensland Electricity Regulations.

## 4.2 Performance

### 4.2.1 Customer Experience

Energex traditionally tracks the customer experience by the number of power quality enquiries it receives. Figure 3 shows that the rate of power quality enquiries has been steadily increasing over the last four years with an average rate of about 15% per annum.

Figure 4 shows a breakdown of the enquiries received by the reported symptoms over the last 12 months, with the largest identifiable category, at 43%, related to solar PV issues. These are usually associated with customer installations where solar PV inverters could not export without raising voltages above statutory limits. Although inverters are designed to disconnect when voltage rises excessively, regular occurrences of this reduce the level of energy exported and often cause voltage fluctuations and customer complaints. As solar PV installations continue, this situation is likely to worsen. Energex is also aware that inverters being installed on its network have default overvoltage protection set points that exceed the required maximum setting of 257 volts specified in the connection agreement. Energex has reminded installers of their obligations to set this protection to avoid appliance damage within the customers' installation from excessive voltage.  Energex is proposing to address non-compliant settings in conjunction with proposed capital and operating programs to address high voltages on the network.

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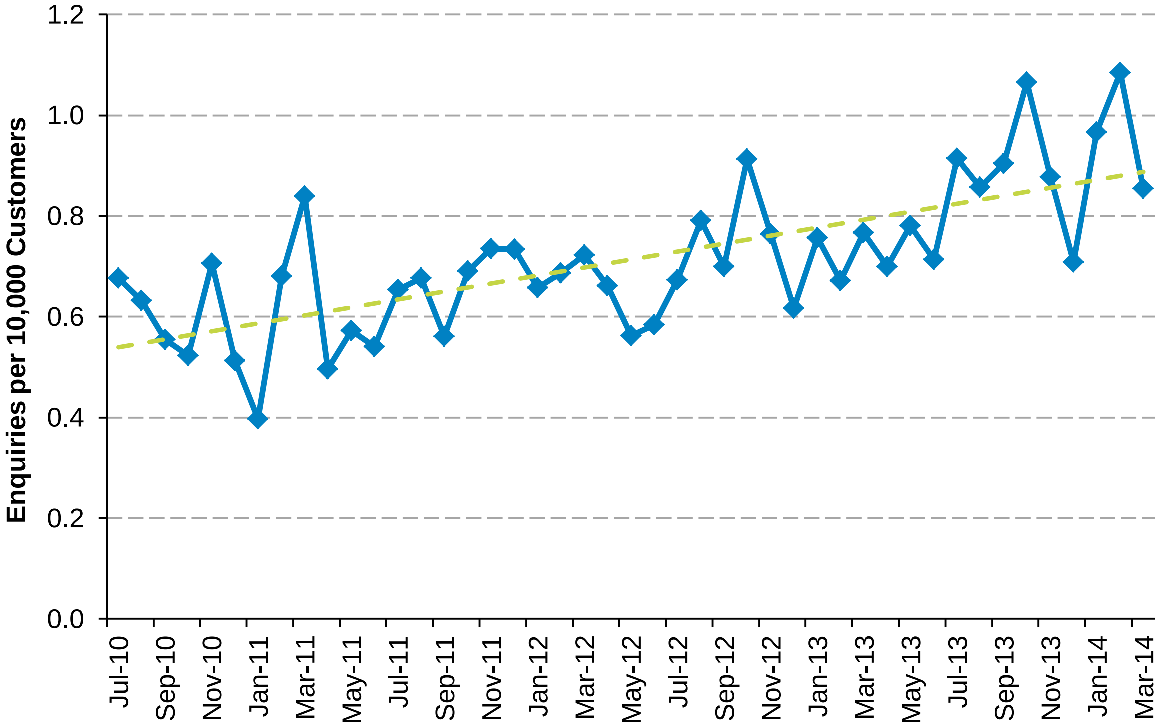


**Figure 3 – Power Quality Voltage Enquiries**

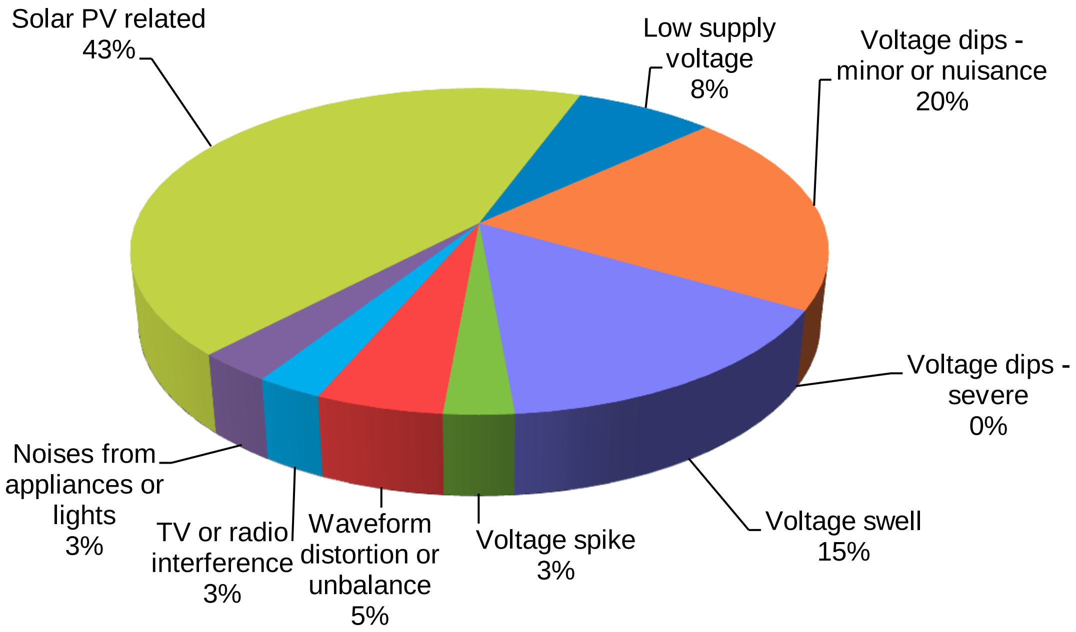


Figure 4 – Power Quality Voltage Enquiries Classified by Symptom (July 10 – March 14)

### 4.2.2 Steady State Voltage Compliance

With the rollout of monitoring equipment to the LV network commenced in the current regulatory period, information has been gathered that demonstrates that during normal conditions, a significant number of sites experience non-compliant steady state voltages. In summary, an analysis at customer and distribution transformer monitored sites in aggregate indicates the following level of non-compliance.

- **9%** of distribution transformers with high V99%, **55%** with V1% below design limits (**647** samples)
- **9.8%** of 3Ø customers with high V99%, **4.9%** with low V1% (**3,275** samples from Jul '08 to Dec '10)
- **1.6%** of 1Ø customers with high V99%, **2.2%** with low V1% (**1,603** samples from Jul '10 to Sep '11
- Similar results from **1,878** customer years' worth of 2012 data for customers.

As a minimum to reset high voltages, this could potentially translate to around 800 distribution transformers (2% of 40,000 distribution transformers) requiring investigation and some level of remedial works.

## 4.3 Drivers

The key driver for the power quality strategy is responding to network voltage impacts arising from the high penetration of Solar PV. Energex has obligations to ensure that such inverter energy systems do not cause a material degradation in the power quality to other network users and do not adversely affect operation of the distribution network. This will require the network to be adapted over time to be able to continue to deliver a safe and reliable service with acceptable power quality.

## 4.4 Issues / Challenges

### 4.4.1 Solar Photovoltaic (PV)

#### 4.4.1.1 Rapid Capacity Growth

The overall growth in solar PV embedded generation has continued despite changes to the feed in tariffs and is continuing to challenge the performance of the distribution network.

Figure 5 shows the historical growth in installed capacity on Energex’s network for systems ≤ 5kW. This growth has been driven predominantly by the incentives under the original 44c/kWh Solar Bonus Scheme (feed-in tariff 9900). The 44c/kWh tariff was replaced by 8c/kWh in July 2012 (feed-in tariff 7500) with the 8c/kWh tariff phased out from July 2014. This is leading to a large number of distribution transformers with high solar PV penetration, 11kV feeders with very little load during the middle of the day and in some cases, 11kV feeders experiencing reverse power flow.

Traditionally, distribution networks around the world were designed to accommodate voltage drops 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 LV systems, in some areas power flows in the reverse direction from the LV to HV 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 feeding network having to be managed to ensure voltage at customer terminals stays within statutory voltage limits.

Given this phenomena, there is emerging evidence that high penetration of solar PV is already causing voltage rise beyond the statutory limit of 240 volts + 6 % (254.4 volts phase to neutral) in particular parts of the Energex network.

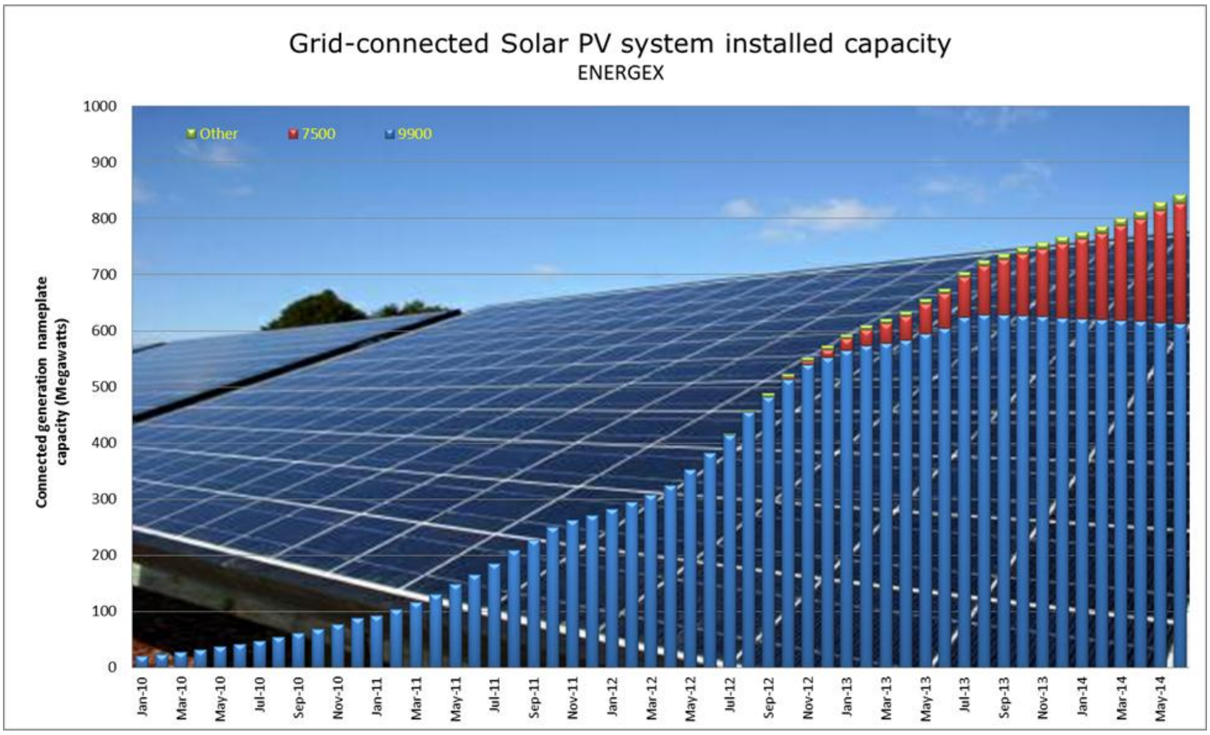


**Figure 5:** **Grid Connected Solar PV System Capacity by Tariff (at 30 June 2014)**

Figure 6 shows the daily load pattern on a residential feeder out of Currumundi zone substation for four consecutive years as the penetration of solar PV systems on this feeder has grown. Despite the 2010 day shown having reduced solar radiation and significant rain, the trend of increasing reduction of load on the feeder during daylight hours is apparent. There also appears to be some evidence of load being shifted away from daylight hours with higher loads in the pre-dawn and evening hours in the latter years. This may be as a result of customer’s changing behaviour to maximise the benefit of the renewable feed in tariffs which are based on net rather than gross solar PV generation. However, there does not appear to be any change to the evening peak in the example shown.

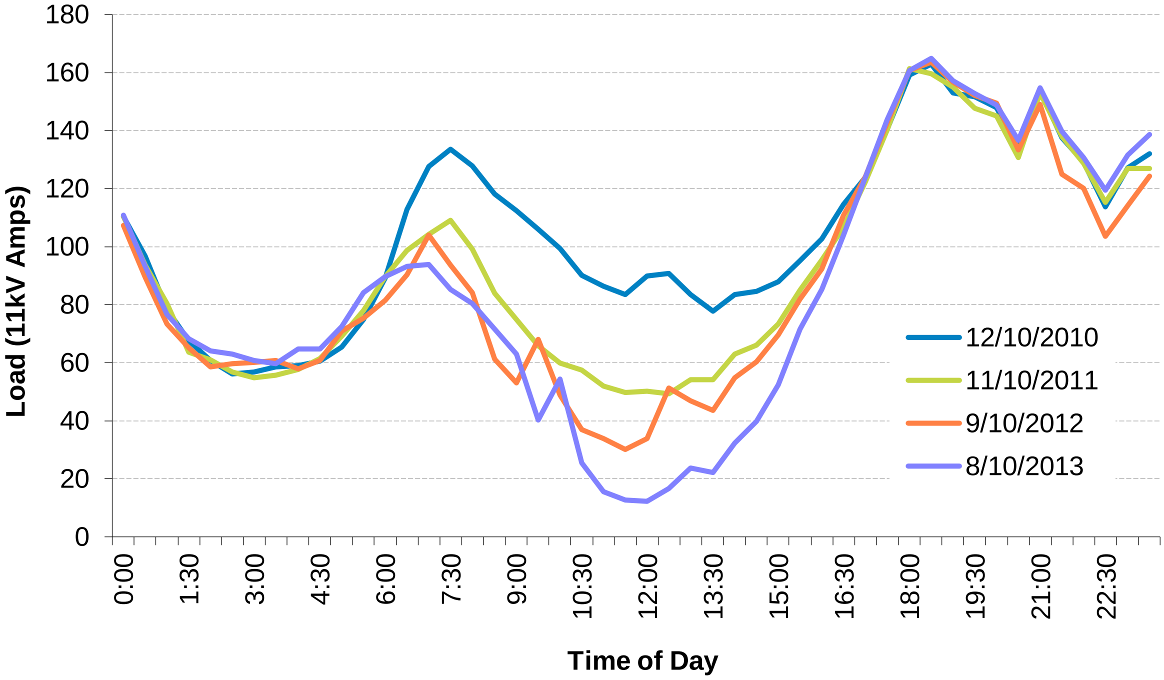


**Figure 6 – Impacts of Solar PV on Currimundi CMD3A (2nd Tuesday in October)**

Figure 7 shows how the number of transformers with high solar PV penetration connected or approved has increased by over 60% in the last 12 months, now representing around 13% of the total population of distribution transformers. Figure 8 reveals what impact this high penetration has on 11kV distribution feeders, with a similar increase and proportion of the population of 11kV feeders with in excess of 1 MW of connected solar PV. Saturation studies indicate that voltage issues can occur once PV penetration exceeds 25%, as it becomes more likely for power flows to reverse during lighter load period in the middle of the day, impacting the ability to manage voltage within statutory limits.

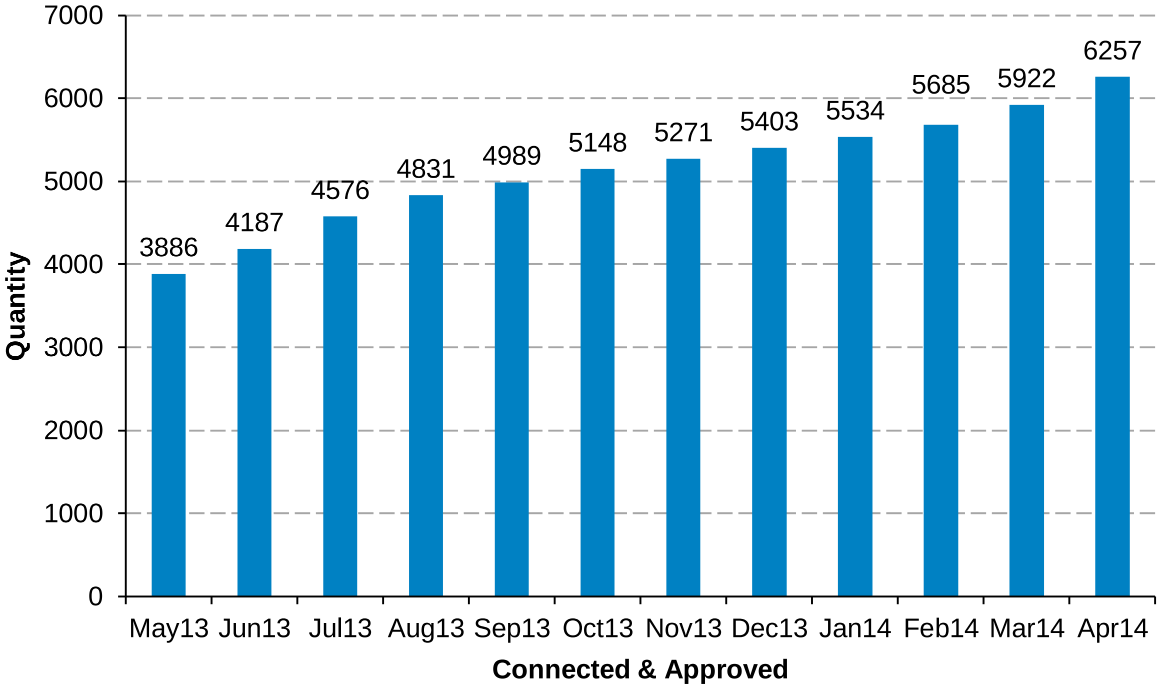


**Figure 7 – Distribution Transformers with Solar PV Penetration > 25% of Nameplate Rating**

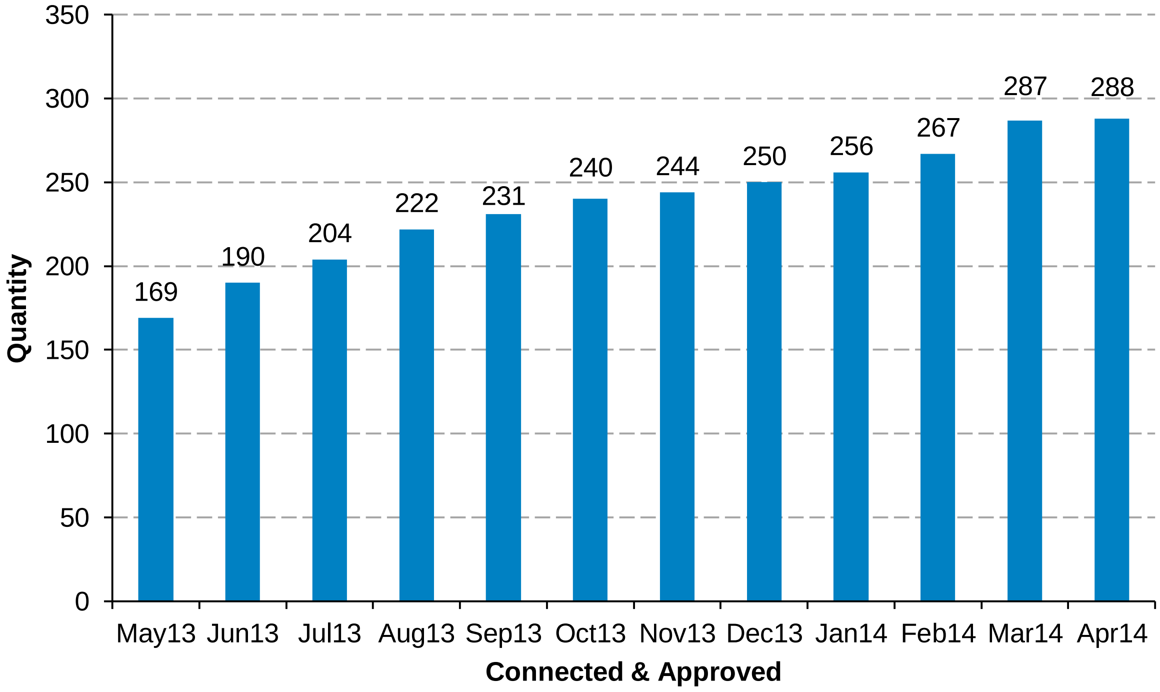


**Figure 8 – Distribution Feeders with Solar PV Penetration > 1000kVA**

Table 1 provides a preliminary forecast of the expected cumulative growth in the number of customer connections and inverter capacity for systems ≤5kW to the end of the next regulatory period 2019/20. The capacity forecast assumes an average inverter rating of 3kW per installation. This growth is assumed to occur in predominantly existing areas of solar PV penetration, with an overall effective increase in connections of around 70% compared to 2013/14 levels.

This forecast assumes current growth rates of around 3,000 inverters per month moderate over the period due to the elimination of the feed-in tariff (FiT). With the drivers being weaker, the forecast assumes that there is still growth underpinned by the solar industry and the incentives offered by retailers at around 1,250 connections per month. The forecast does not factor in the influence of energy storage systems as their uptake is considered low within this period without further reduction in storage costs or some incentive arrangements.

**Table 1: Forecast of Total Solar PV Connections and Growth 2015-20 (systems ≤ 5kW)**

| **Actual** | | **Forecast** | | | | | |
|---|---|---|---|---|---|---|---|
| **2012/13** | **2013/14** | **2014/15** | **2015/16** | **2016/17** | **2017/18** | **2018/19** | **2019/20** |
| **Number of connections** | | | | | | | |
| 221,000 | 262,000 | 294,000 | 324,000 | 354,000 | 384,000 | 404,000 | 419,000 |
| **Installed Capacity (kVA)** | | | | | | | |
| 666,000 | 822,000 | 924,000 | 1,026,000 | 1,129,000 | 1,231,000 | 1,390,000 | 1,352,000 |

#### 4.4.1.2 Increased Voltage Regulation

To illustrate the impact of solar PV on voltage regulation along an LV circuit, the simple model shown in Figure 9 was developed. The model assumes 10 customer evenly distributed with 300 metres of Moon conductor on a 315 kVA 4% impedance transformer, peak load (ADMD = 3 kW) and light load (After Diversity Lowest Demand ADLD = 0.5 kW) . As a best case, conditions were examined on a balanced network. With three such radials of 30 kW load per phase per node, the total transformer load is 270 kW and simulates a heavily loaded transformer. Light load conditions have been supplemented with PV generation of 2 kW per node to simulate the impacts of high PV penetration. The model is also conservative in that it does not include the effect of voltage drop and rise in the customer's LV service.

Figure 10 illustrates for the peak load no generation and balanced load scenario, how voltage drop varies along the main LV circuit. Networks have been traditionally designed for voltage drop, and in the Energex Supply and Planning Manual a design allowance of 11V (4.5%) for overhead designs and 10V (4.1%) for underground designs is stipulated, which limits the length and size of mains that can be utilised. Figure 11 illustrates how the voltage rise varies along the main LV circuit for the low load, peak balanced generation scenario.

The combination of voltage drop and voltage rise, means that the overall voltage regulation to the customer has been increased for which no provision was made in the original design. In practice, the ability to absorb solar PV generation without issue will be very dependent on how loaded the networks are compared to design limits and how long the LV circuit are from the transformer terminals.

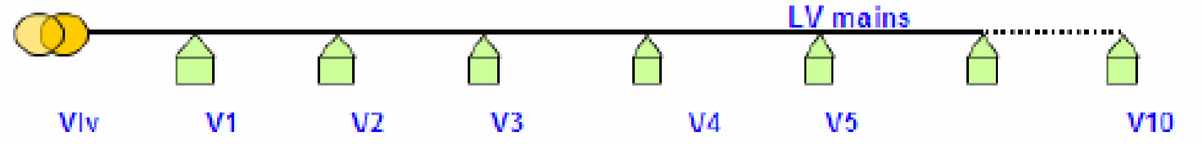
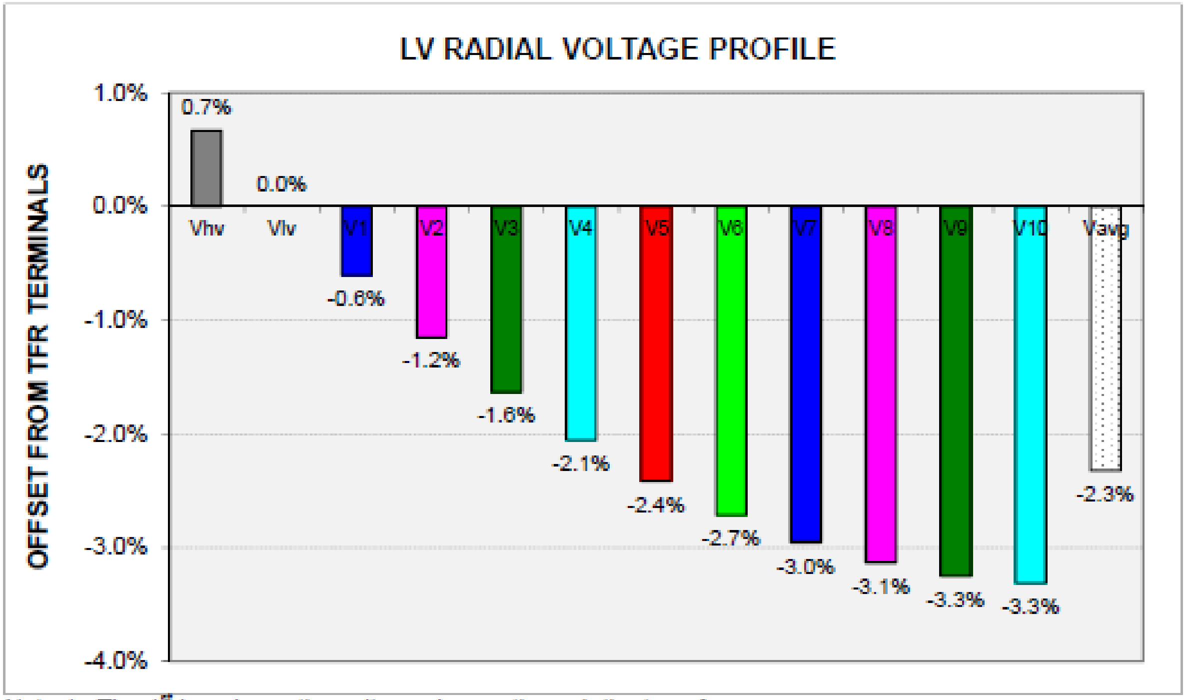
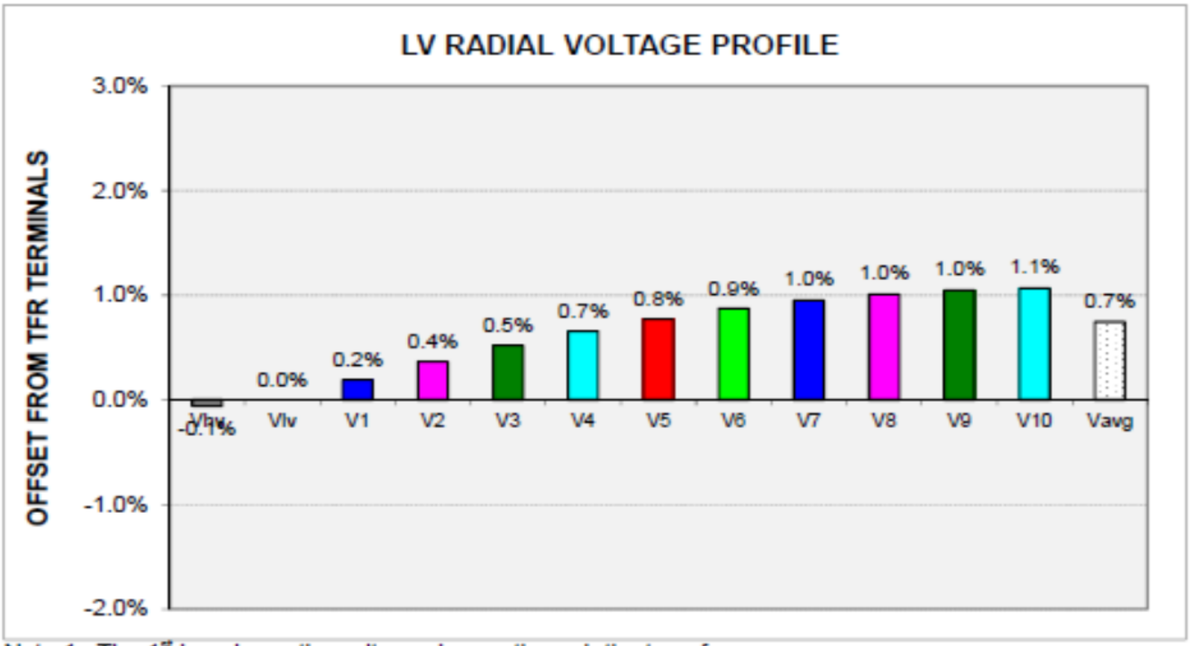


**Figure 9: LV Voltage Profiles with and without Solar PV (Model for Fig. 10 & 11)**



Note 1: The 1st bar shows the voltage change through the transformer.
Note 2: The far right bar shows the average voltage offset from the transformer LV terminals.

**Figure 10: LV Voltage profiles with and without Solar PV (peak load)**



Note 1: The 1st bar shows the voltage change through the transformer.
Note 2: The far right bar shows the average voltage offset from the transformer LV terminals.

**Figure 11: LV Voltage Profiles with and without Solar PV (light load)**

To investigate saturation limits for solar PV generation on existing networks, a study was conducted in 2012 by Western Power under its Perth Solar City Program. The study found that small scale residential solar PV penetration levels of around 30% (with respect to the rated capacity of supply) caused voltage excursions outside the statutory voltage limits for homes towards the end of the LV distributors.

In 2011 Energex commissioned Evans & Peck (E&P) to provide advice on what might be reasonable policy settings for the assessment of solar PV applications. As part of this advice, a number of theoretical models were established.

E&P modelled two distinct low voltage networks – one based on an idealised urban network, and one based on a semi – rural network where voltage issues associated with a relatively large PV installation had arisen.

The urban model consisted of the following items:

- 250KVA 11kV/415V Distribution Transformer;
- 600m of 4 wire ‘Moon’ (7/4.75 AAC) overhead line. Two 300m circuits;
- Consumer mains 6 sqmm Aerial cable;
- 50m pole spacing’s with 6 consumers lumped at each pole;
- Load profile consistent with measured results
- Solar generators are 1.5kW nameplate rating with output consistent with average of measurement results; and

The rural model consisted of a 30kW 3 phase Solar PV inverter installed at the end of a moderately long LV line as follows:

- 100KVA 11kV/415V Distribution Transformer;
- Three circuits. ‘A’ Feeder = 442m, ‘B’ Feeder = 278m, ‘C’ Feeder = 295m;
- 737m of 4 wire ‘Moon’ or ‘Mars’ overhead line. 278m of Bundled overhead ;
- Consumer mains (150m) are modelled for the 30kW solar installation (25mm2) ;

- The 30kW system is at the end of the 'A' Feeder. There is also a 1.5kW system at the end of the 'B' Feeder;
- Load Profile is consistent with average values obtained from measured substation load data;

Figure 12 shows the results of the E&P model for the urban network where high penetration occurs. It shows voltage over a synthetic 2 day period – one representing the February peak load and the other representing a day in October when PV output is high but residential load is low. It shows voltage could be expected to be outside limits for high PV penetration (50%).

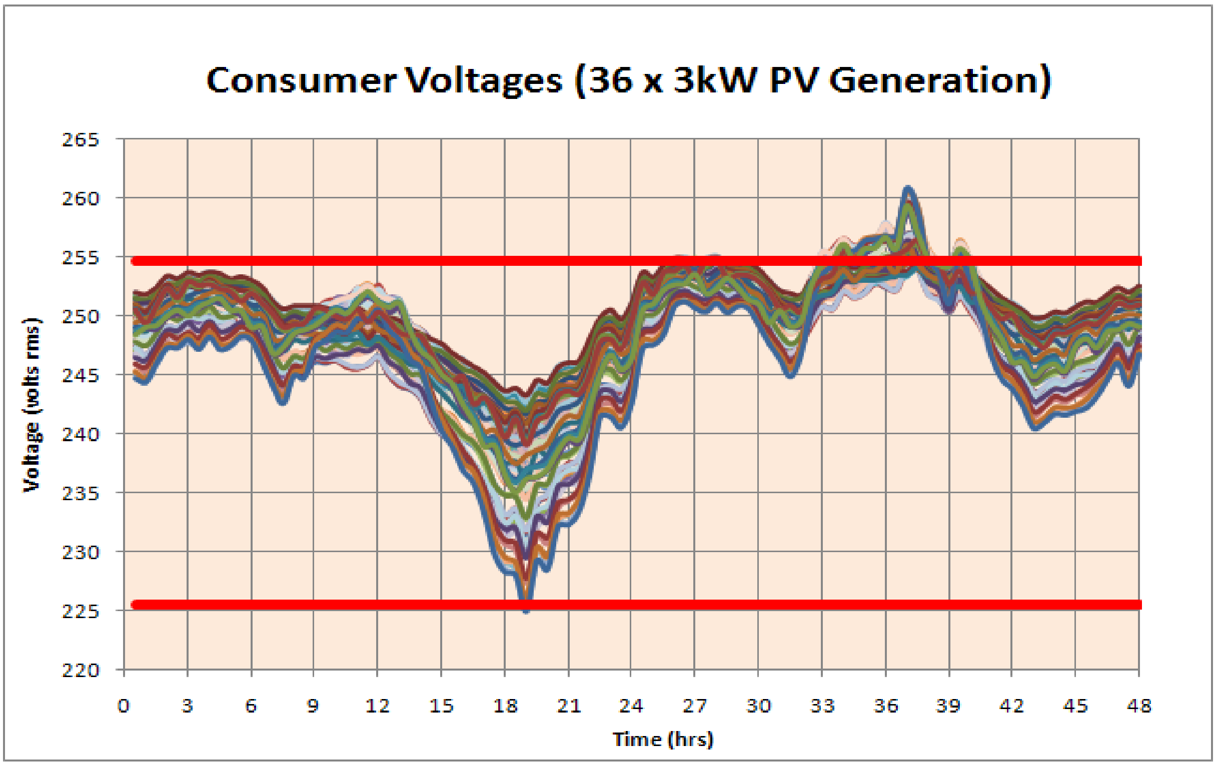


**Figure 12: Customer Voltage Profile – 50% PV Penetration – Urban**

Figure 13 demonstrates similar over-voltages for the semi-rural model, but in this case it is driven by the single large PV. The PV installation itself is exposed to voltage levels approaching 265Volts which would cause nuisance tripping of the inverters for the case where the protection is set in accordance with Energex's connection agreement (255V or 257V). In this particular case there will be approximately 10 Volts rise in PV Generator underground mains. There are no customers at this point and therefore this elevated voltage is satisfactory. However the customers at the end of this line will see maximum voltages near the top limit. It will not be viable to lower the voltage by tap adjustment since the minimum voltage under peak load is too close to the minimum level of 225V.

E&P concluded that, within the current network configuration, there is a maximum penetration that should be permitted in the absence of detailed interconnection studies. While E&P's advice was in the context of connection policy, it is also a very strong indication that Energex may need to investigate and remediate areas of the network with high PV penetration. Since the modelling assumes typical network topology (lengths and size conductors), lower levels of penetration are also likely to cause problems in some parts of the network. Based on this work, Energex's believes a 40% penetration level is a good guide to where voltage problems may be experienced, and the basis for more detailed measurement and / or modelling.

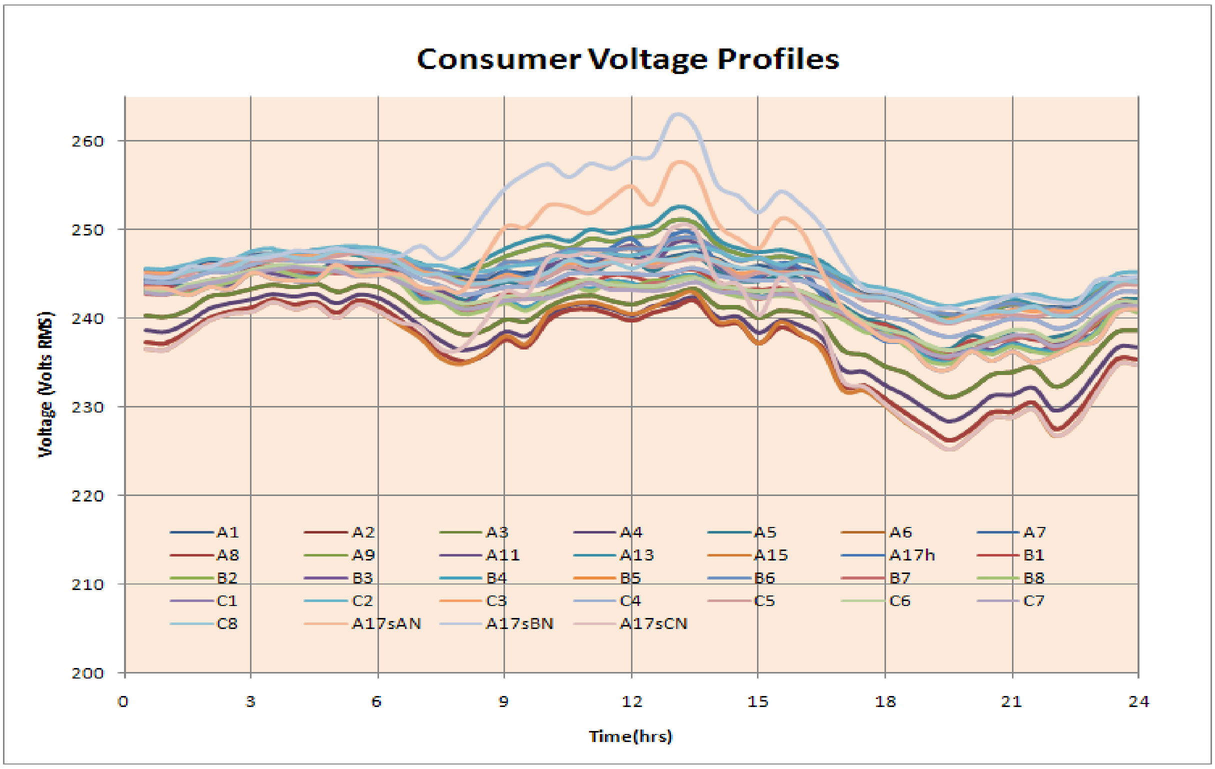


**Figure 13: Customer Voltage Profiles – Rural Network with 30kW PV system**

Energex has recently undertaken some measurements at customer sites towards the end of LV circuits in high penetration areas. Figure 14 shows measurements at P36380, Bundamba monitored over a period of one week.  The site is in a semi-rural area towards the front of the 11kV feeder (refer details).  The LV circuit has a PV penetration of 72% off a 100 kVA transformer with 24 inverters connected.

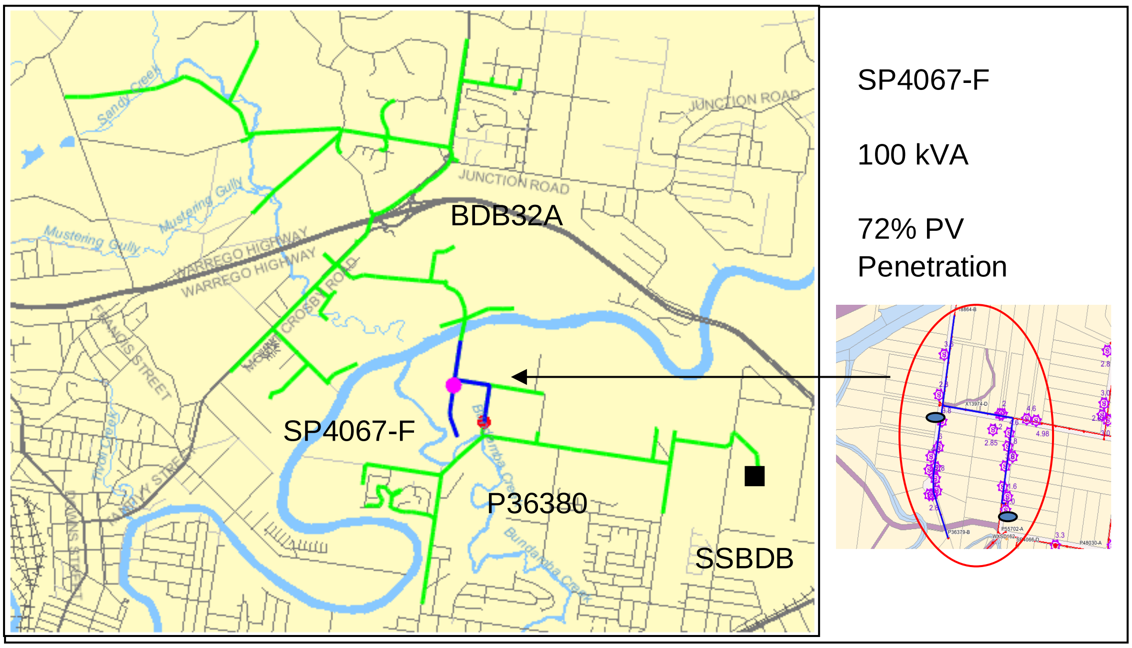


Figure 14: Measurements at P36380, Bundamba

Figure 15: LV Circuit Voltage Monitoring Site Hart Street, Bundamba

Figure 15, Figure 16, Figure 17 show the analysed voltage results against a 24 hour cycle. The solid line for each phase is the 7 day average with the minimum and maximum to show the upper and lower bounds of the variation. This clearly shows the possibility of voltages in high PV areas approaching and exceeding statutory limits on particular days on particular phases even though the weekly averages may be within limits. Figure 18 shows the average voltage compared for each phase clearly illustrating the underlying difference in the phase balance.

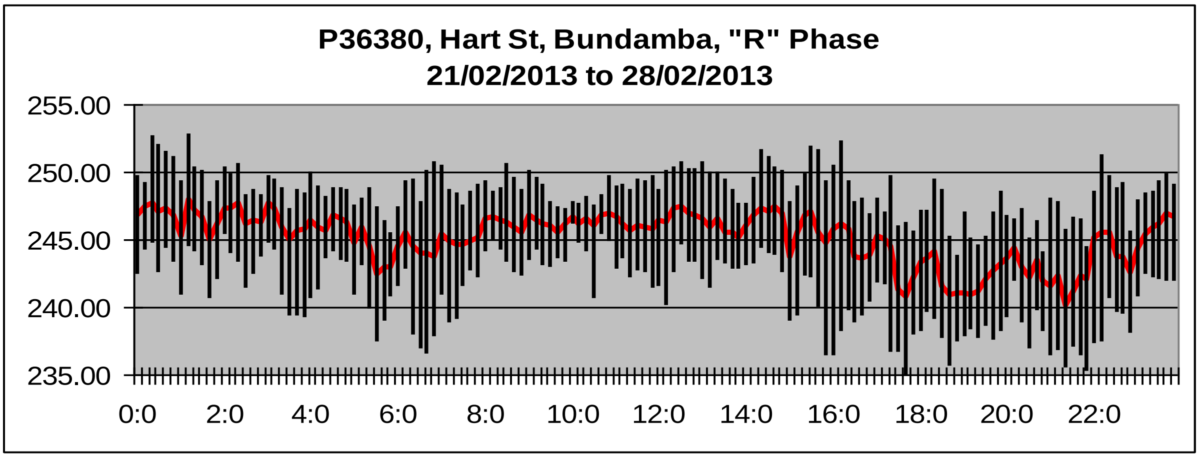


Figure 15: LV Circuit Voltage Monitoring Site Hart Street, Bundamba

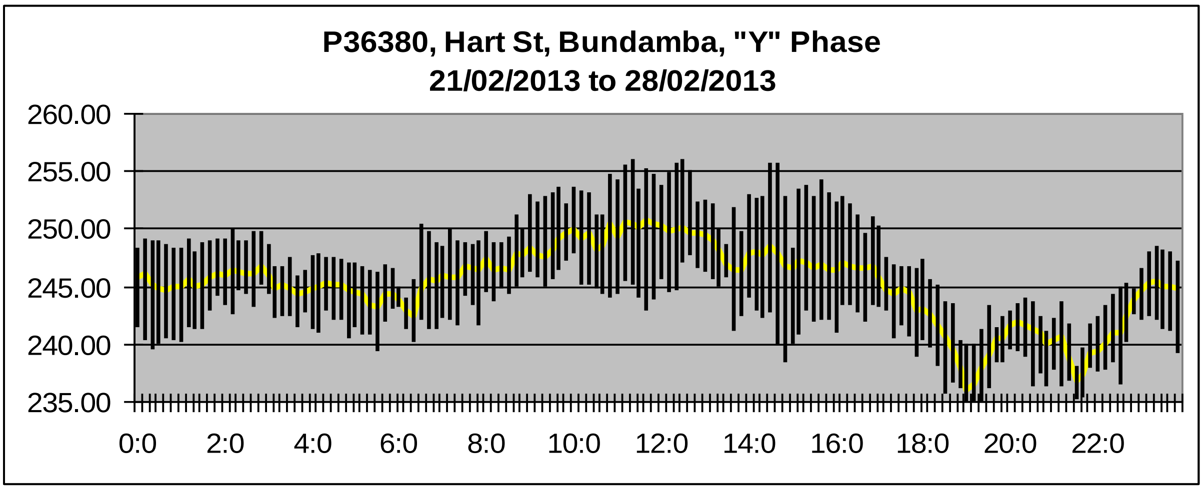


Figure 16: LV Circuit Voltage Monitoring Site Hart Street, Bundamba

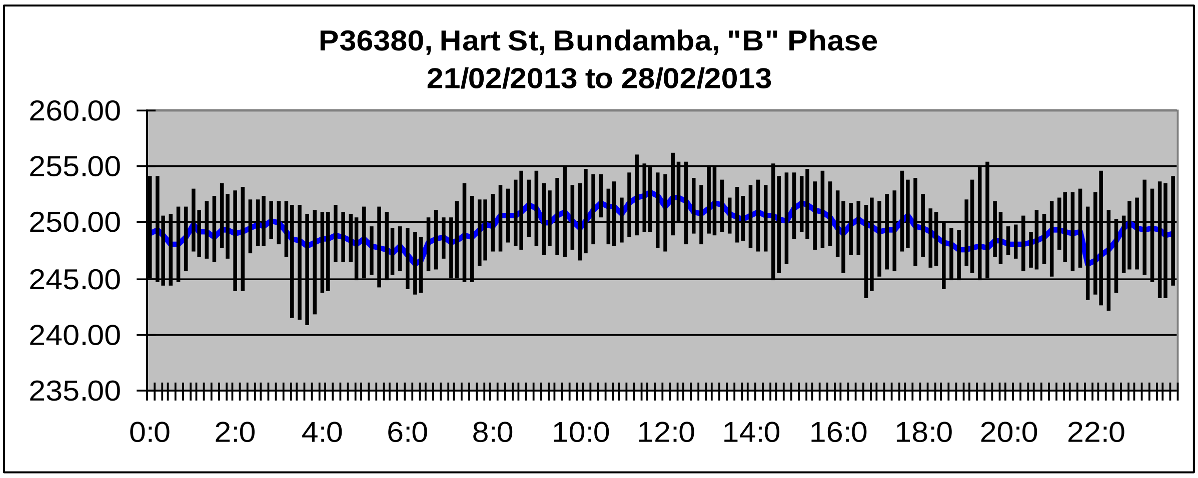


Figure 17: LV Circuit Voltage Monitoring Site Hart Street, Bundamba

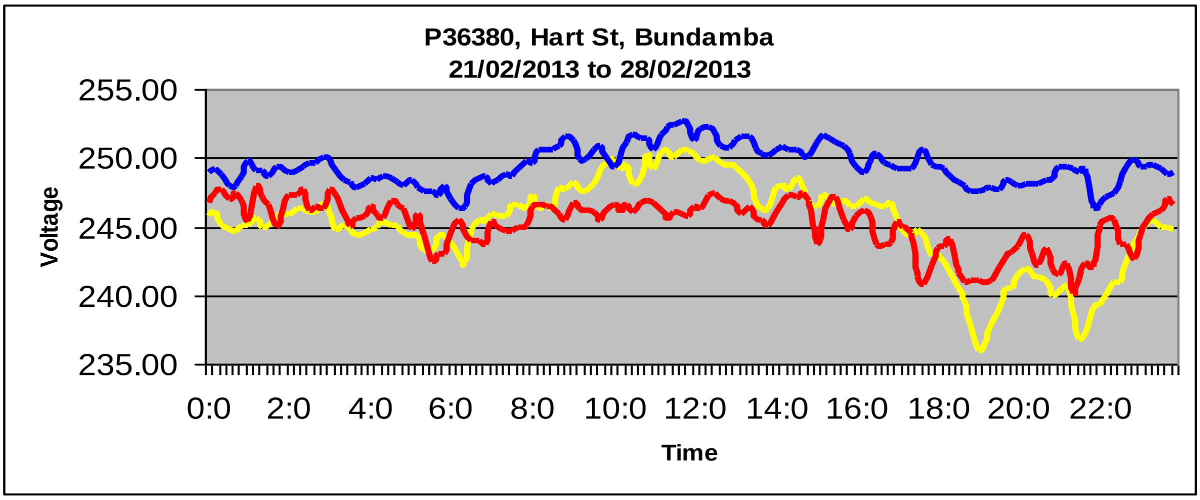


Figure 18: LV Circuit Voltage Monitoring Site Hart Street, Bundamba

#### 4.4.1.3 Non-Compliant Inverter Overvoltage Protection Trip Settings

Under Energex's IES Network Connection Agreement for inverters in the 0-5 kW range, customers through their installers are required to ensure that the inverter has its overvoltage protection trip settings configured correctly (255V in early agreements, 257V in later agreements).

The largest PV inverter supplier in SEQ recently confirmed in writing that their default over-voltage protection settings are either 265V or 270V. Given that there are anecdotal reports that few if any installers have been altering these to align with the connection agreement, it is highly likely that a large proportion of the 200,000 plus inverters from this supplier on the network are not configured properly.

This poses a risk of producing high voltage on the LV network in areas where there are high concentrations of PV. This may increase the likelihood of LV circuit voltages being above the statutory voltage limit in some areas, damage to customer appliances as per previous insurance claims and a possibility of fire in extreme cases.

This issue will need 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. Energex 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.

#### 4.4.1.4 Number of Areas Impacted

Energex has almost 48,000 distribution transformers with 28,000 of these currently having solar PV connections, the majority on residential rooftops. Saturation studies indicate that voltage related issues are more likely to occur (on average) for customers connected towards the end of LV circuits with excessive lengths (e.g. >700 metres) when penetration levels exceed around 40% of the transformer rating. The additional voltage regulation due to the Solar is very dependent on the actual network but is known to be worse in areas with overhead construction and longer lengths of LV circuit. This does not preclude voltage issues from occurring on areas with less PV penetration and shorter lengths of LV, but is statistically less likely. The additional voltage regulation has to be managed within the overall 12% voltage range at customer terminals.

Accordingly solar PV exceeding 40% penetration but with shorter lengths of LV (400-700 metres) but still longer than average, are likely to have less of an impact. Similarly solar PV with penetration in the 25%-40% range is also likely to have less of an impact. Given the continued growth in solar PV expected over the next five years, areas with 25% penetration are likely to reach the 40% threshold over this period and areas with 15% penetration are likely to reach the Energex planning limit of 25%.

Table 2 summarises the number of areas of the network likely to be impacted. These are classified as either Priority P1 or P2, with P1 expected to have a higher impact on voltage regulation than P2 areas. Programs of work have been developed to address both P1 and P2 areas.

Table 2: **Number of Forecast Transformer Areas Impacted 2015-20**

| Index | Classification | Criteria | Thresholds | Forecast No of LV Transformer Areas 2015-20 |
|---|---|---|---|---|
| 1 | P1<br>(High) | PV Penetration | >40% | 5,400 |
| 2 |  | Circuit Length | >700 metres | 4,300 |
| 3 |  |  | AND | 900 |
| 4 | P2 - a<br>(Moderate) | PV Penetration | >40% | 5,400 |
| 5 |  | Circuit Length | 400-700 metres | 9,000 |
| 6 |  |  | AND | 2,400 |
| 7 | P2 - b<br>(Moderate) | PV Penetration | 25-40% | 6,000 |
| 8 |  | Circuit Length | >700 metres | 4,300 |
| 9 |  |  | AND | 1,100 |

### 4.4.2 Distribution Transformer Tap Profiles

Like most Distributors, Energex has traditionally selected a distribution transformer tapping plan based on peak load conditions. The problem with this approach is that it does not consider light load scenarios. Furthermore, whilst light load conditions occur almost daily, peak loads as per the 50 PoE definition occur only once in 2 years and 10 PoE once in 10 years. One outcome of such a design approach is that regular light load conditions may produce high voltages that exceed statutory limits. This is exacerbated by high penetration of solar PV on the LV network.

Figure 19 demonstrates this by displaying the calculated no load LV terminal voltages of distribution transformers sited all along a feeder with 3% voltage boost at the substation bus from the Line Drop Compensation (LDC) settings and 7% voltage drop allowance. If the transformer taps are set as recommended for peak load, then the solid red and solid blue lines indicate the maximum and minimum terminal voltage respectively. The changes from one tap to another along the feeder occur when the line rises rapidly between consecutive points.

This shows that transformers in the latter part of the feeder (from 5% to 7% VD) will experience voltages in excess of statutory limits under light load conditions. This cannot be mitigated by altering transformer size or length or impedance of LV. Furthermore with light load occurring daily, the excursion will be regularly experienced by customers close to the transformer terminals.

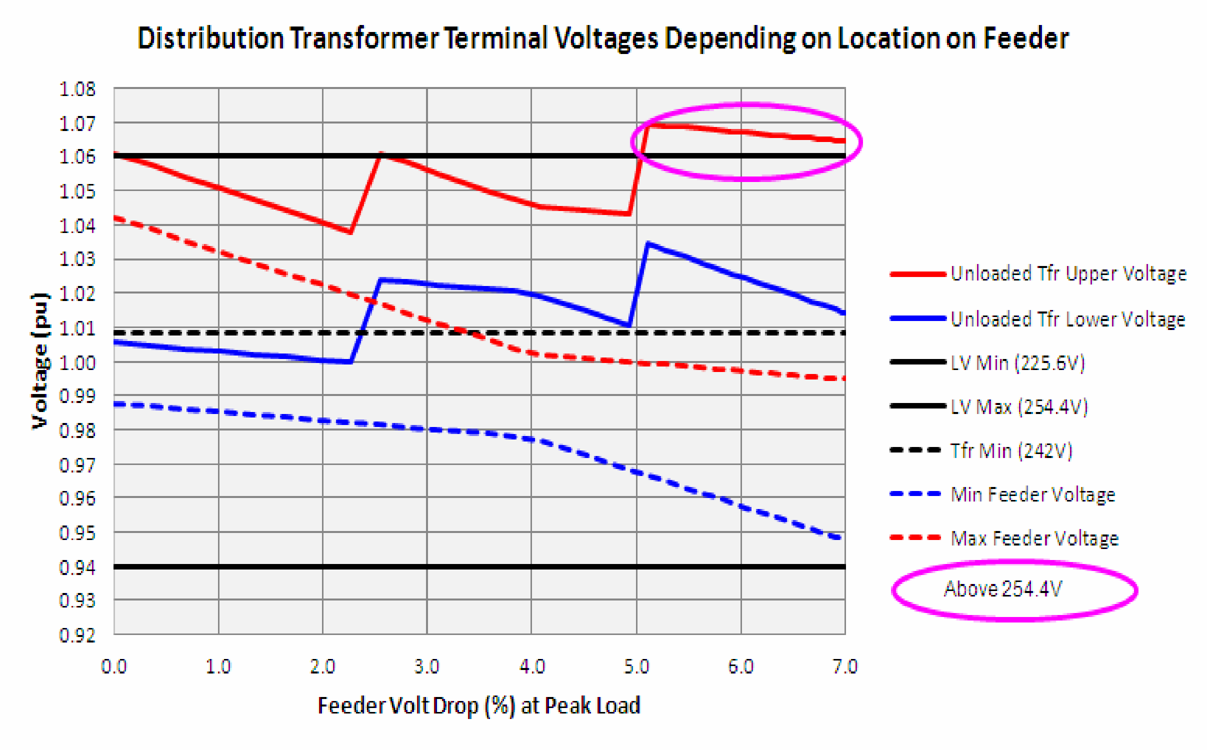


**Figure 19: Unloaded Transformer Secondary Voltages along the Feeder with 3% LDC, 7% VD, 2.45% BW, Taps 4, 5 & 6 on 7 Step 2.5% Tap Transformers**

Energex has done some preliminary desktop analysis of distribution transformer tap position based on the data that is currently stored in NFM, although the quality of this data is in question due to poor record keeping and field process deficiencies. The 11kV 50PoE Summer Day voltage regulation (last updated April 2013) for every distribution transformer was used to determine a recommended tap setting based on the existing tapping plan criteria in the planning guidelines. The calculated tap position was then compared to the recorded tap position. The preliminary results are as follows:

Out of the 33,977 transformers with sufficient data (14,000 were excluded),

- 25,708 (or 76%) are tapped too high;
- 2,380 (or 7%) are tapped too low;
- 5,875 (17%) are tapped correctly.

Although the quality of the data will be a contributor to this result, it is likely that some systemic issues have arisen with generally raising the tap, perhaps over a period of time as loads have increased and customers may have complained of low volts. Resetting taps correctly would produce much lower voltages and be more compatible with solar PV inverters.

The next step will be to verify this analysis by obtaining reliable tap position information from field data capture programs and improving the tap setting plan process from the planning phase through to field deployment.

### 4.4.3 Phase Unbalance

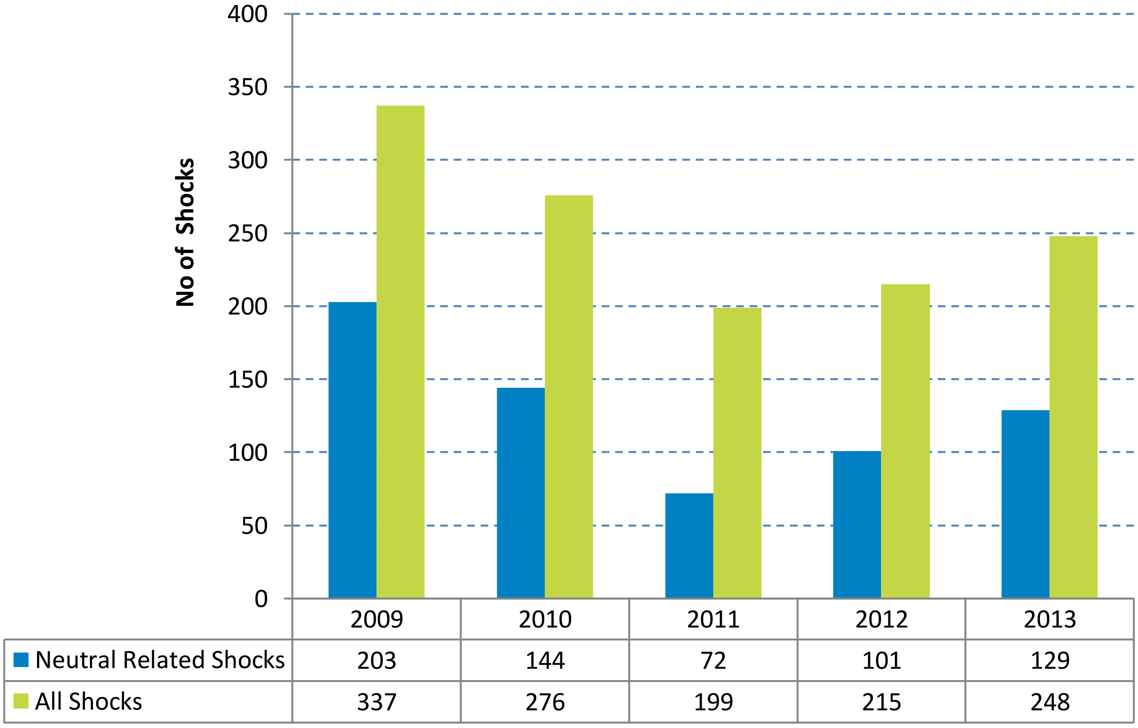
Phase unbalance due to historically poor work practices connecting customers to the overhead network has been previously identified as an issue on the Energex network. A substantial and sustained rebalancing program is required to remediate target areas to ensure:

- three phase voltage are maintained within the NER requirements;
- single phase voltages on the low voltage network are maintained within statutory limits;
- neutral currents leading to shock complaints are minimised.

Rebalancing has commenced in the current regulatory period 2010-15 and will need to continue in successive periods due to the large resourcing commitment needed to complete this work.

### 4.4.4 Neutral Integrity

Due to the impacts of ageing networks and environmental factors (eg corrosion), the integrity of Energex’s neutral system can be impacted over time. The number of neutral related shock enquiries from 2009 to 2013 (calendar years) is shown in Figure 20 and makes up around 50%-60% of the total shock enquiries investigated and reported by Energex in its corporate safety system ‘eSafe’. The number of neutral related shock enquiries in 2013 was 129. Although Energex’s existing processes rectify these types of faults once known, there is potential for hazards to remain undetected. A monitoring system using customer smart meters is proposed to address this issue. A similar scheme has been successfully trialled in Victoria following the mandated smart meter roll-out.



| | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|
| 🟦 Neutral Related Shocks | 203 | 144 | 72 | 101 | 129 |
| 🟩 All Shocks | 337 | 276 | 199 | 215 | 248 |

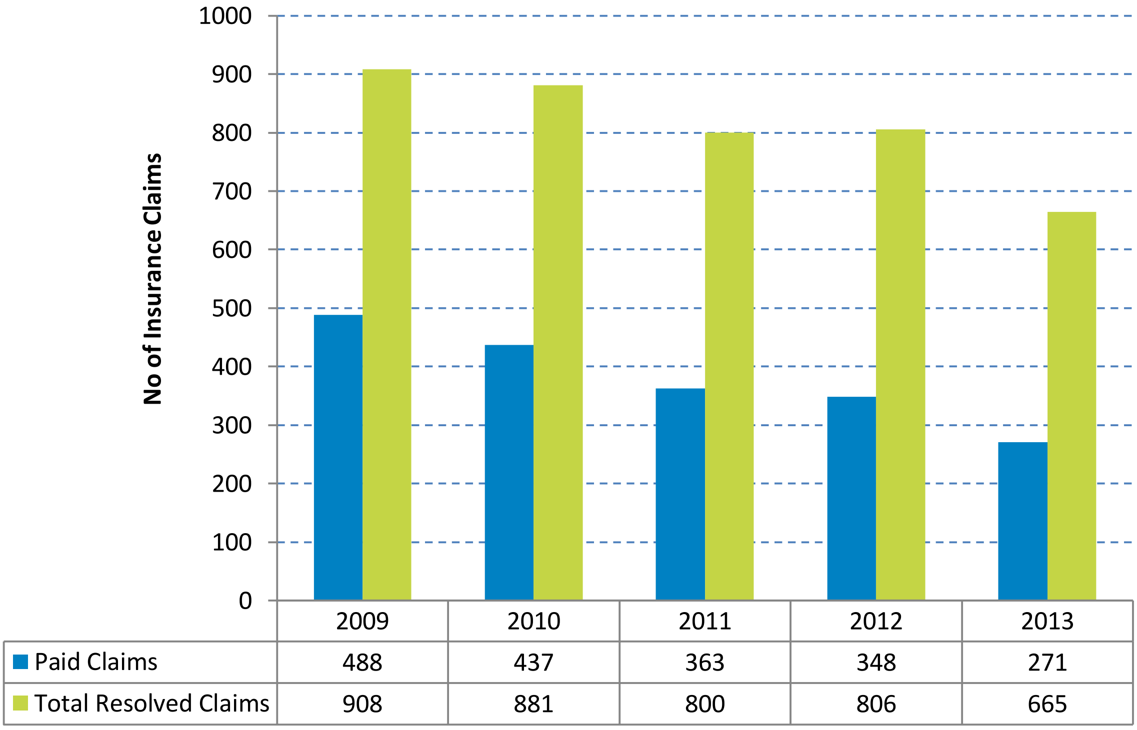
**Figure 20 - CA50 – Neutral Related Shock Complaints**

### 4.4.5 Extreme Voltages

Extreme voltage due to network events can increase the risk of an electrical fault in the customer's premises which could then lead to equipment and appliance damage and potentially house fires.

Figure 21 shows the number of paid insurance claims from 2009 – 2013 (calendar years), representing around 40% of the total resolved claims in 2013 of 248. Figure 22 shows the number of power quality enquiries from July 2010 to March 2013 with a steadily increasing rate due to the influence of Solar PV on high voltage. Substation equipment failure has resulted in more than 4 substation events affecting many thousands of customers being exposed to potential hazards in the last two years. Faults on the network, particularly during storms with trees falling on power lines, can also result in high voltage (11kV or 33kV) being imposed on LV conductors. These events affect smaller numbers of customers but are more frequent (at least 5 p.a. average in last five years in eSafe), and contribute to a portion of the insurance claims shown in Figure 21.

A monitoring system using customer 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.



| | 2009 | 2010 | 2011 | 2012 | 2013 |
|---|---|---|---|---|---|
| 🟦 Paid Claims | 488 | 437 | 363 | 348 | 271 |
| 🟩 Total Resolved Claims | 908 | 881 | 800 | 806 | 665 |

**Figure 21 - CA50 – Insurance Claims**

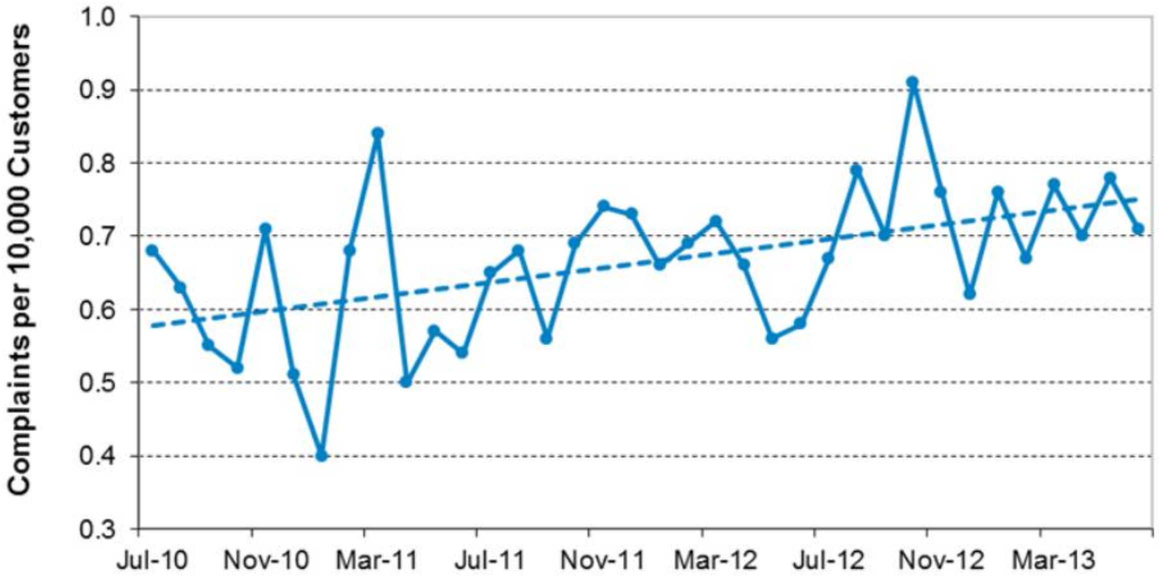


**Figure 22 - CA50 – Power Quality Enquiries**

## 4.5 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 that is used. The impact of overvoltage and under-voltage on customer equipment is discussed in the following sections.

### 4.5.1 Overvoltage Impacts

There is little quantitative data showing the impact of high voltage on typical customer household appliances and equipment. EPRI (USA) in 2005 and Norway in 2009 tested appliances at various elevated voltages but for short times. These tests indicated a good resistance of equipment under these conditions, but for longer times, it is thought that lifetimes will be reduced. At much higher voltage levels, fire is also a risk.

Data presented in a CIRED International Conference paper in 2011 is shown in Figure 23 and Figure 24. 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.

### 4.5.2 Under-voltage Impacts

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. A reduction in voltage from 240V to 230V (4%) will reduce output heat energy by about 8% (1-0.962) increasing required heating time and reducing electricity power demand. Resistive heating devices are unlikely to significantly change electricity energy consumption or customer cost due to reduced voltage since the energy (kWh) required to boil water, for example, is unchanged.

Old electrical motors and pumps, designed for 240/415V, may overheat or malfunction if exposed to voltage in the range 205V-216V when starting or 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 under-voltage, 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. If an old motor, driven near full load, was exposed to 216V for 2 hours per day, its remaining life could be reduced by a further 20%. It may also fail to start or stall under heavy load when voltages fall below the motor's specification.

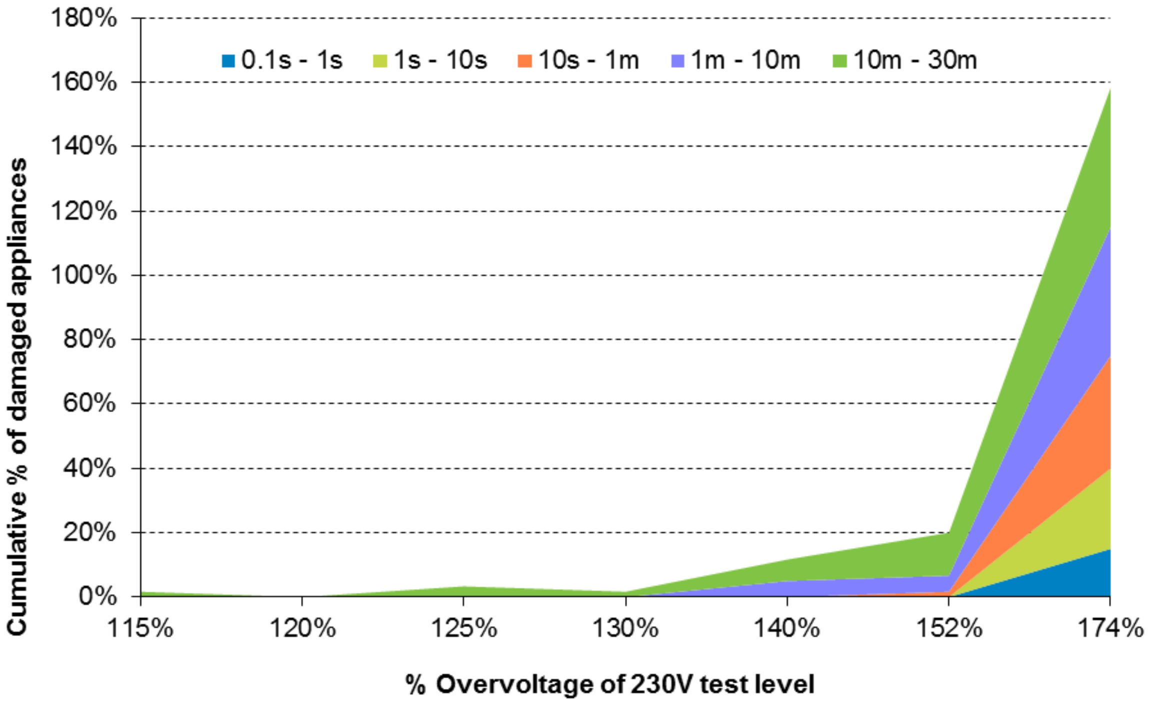


**Figure 23: CIRED Paper Overvoltage Appliance Testing**

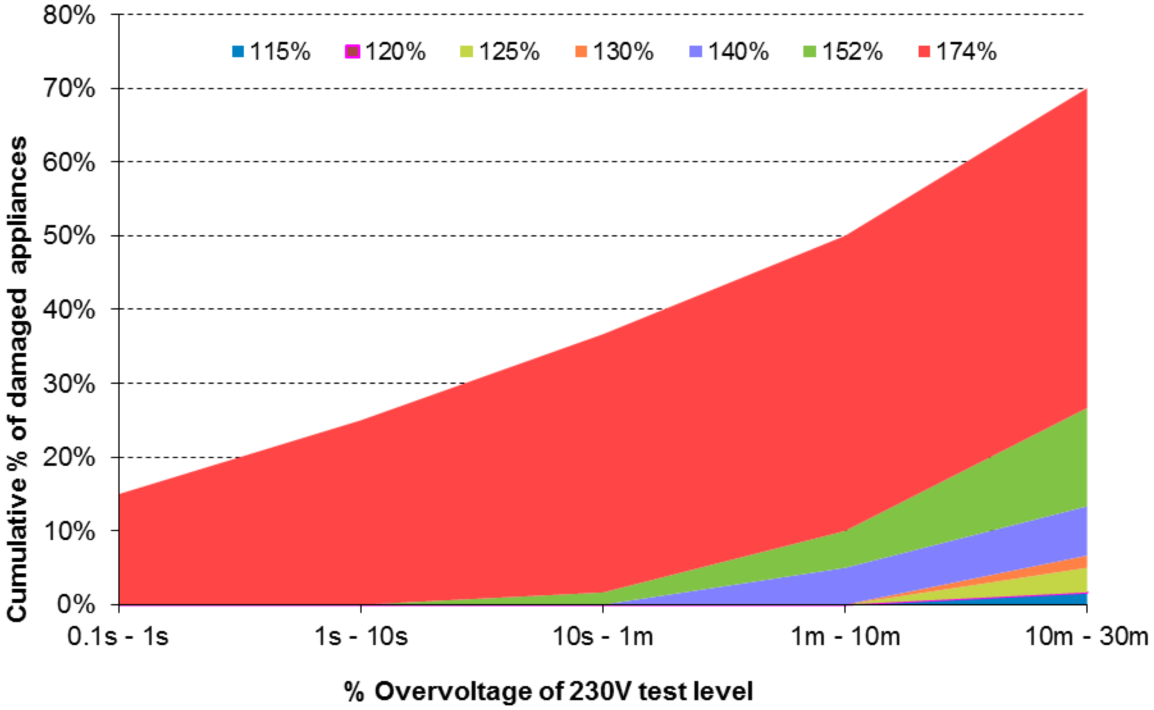


Figure 24: CIRED Paper Overvoltage Appliance Testing

# 5 Future Requirements

## 5.1 Core Deliverables

In order to address the key drivers, issues and challenges, Energex needs a greater knowledge and understanding of the performance of the low voltage network with respect to its obligations and the changing environment. This will allow the areas of the network requiring remediation to be identified and a range of program initiatives deployed to mitigate the impact in worst performing areas.

## 5.2 Changing Environment

### 5.2.1 230 Volt 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 voltage standard, IEC 60038:1983. Energex’s existing legislated standard is 240 +6% / -6% volts.

The main difference between the 230V standard described and present 240V standard is:

- The maximum supply voltage would reduce from 254.4V to 253.0V;
- The minimum supply voltage would reduce from 225.6V to 216.2V; and
- The minimum utilisation voltage would reduce from 213.6V to 204.7V (due to an additional 5% voltage drop allowed in the premises as per AS3000).

Since the introduction of the standard, there has been a mixed range of responses from Australian Distributors. Table 3 shows a State by State comparison of the legislated voltage standards adopted by each distributor. This shows that all of VIC, TAS and SA have adopted the new standard in full. Apart from QLD, only WA and NSW effectively maintain the 240V standard. In the case of NSW two of the companies have rebadged to 230V but are maintaining the same voltage range of 12%.

**Table 3: State by State Comparison of Voltage Requirements**

| State | Distributors | Nominal Volts | Range | |
|---|---|---|---|---|
| | | | Upper | Lower |
| QLD | Energex, Ergon | 240V | +6% | -6% |
| NSW | Essential Energy,<br>Endeavour Energy | 230V | +10% | -2% |
| NSW | AusGrid | 240V | +6% | -6% |
| ACT | ActewAGL | 240V | +6% | -6% |

| State | Distributors | Nominal Volts | Range | |
|---|---|---|---|---|
| | | | Upper | Lower |
| VIC | Citipower, Jemena, Powercor, SPAusNet | 230V | +10% | -6% |
| TAS | Aurora Energy | 230V | +10% | -6% |
| SA | ETSA Utilities | 230V | +10% | -6% |
| WA | Horizon Power, Western Power | 240V | +6% | -6% |
| NT | PowerWater | 230V | +10% | -10% |

Figure 25 illustrates the generalised impact of changing from the 240V standard to the 230V standard. For indicative purposes only, it assumes that 2% of customer sites have voltage outside upper limits and 2% of customer sites have voltage outside lower limits. In reality there will be a portion of customer sites that go outside both higher and low limits that would need to be accounted for. This type of analysis indicates that changing the voltage standard from 240V to 230V with no other changes to voltage profiles will potentially increase the number of high voltage non-compliant customer sites (red curve compared to 253V limit). However, the number of non-compliant low voltage sites would be reduced to zero in this case.

Given that Energex's driver is to be able to address high and low voltage regulation, dropping the voltage profile either at the 11kV bus / feeder level or distribution transformer tap settings may result in the red curve shifting to the green curve. In reality this is a very over simplified representation, as not all areas of the network may be changed unless there is a need due to costs and resources involved. However, as a generalised case, it shows that shifting to the green curve could help to address both high and low voltage compliance.

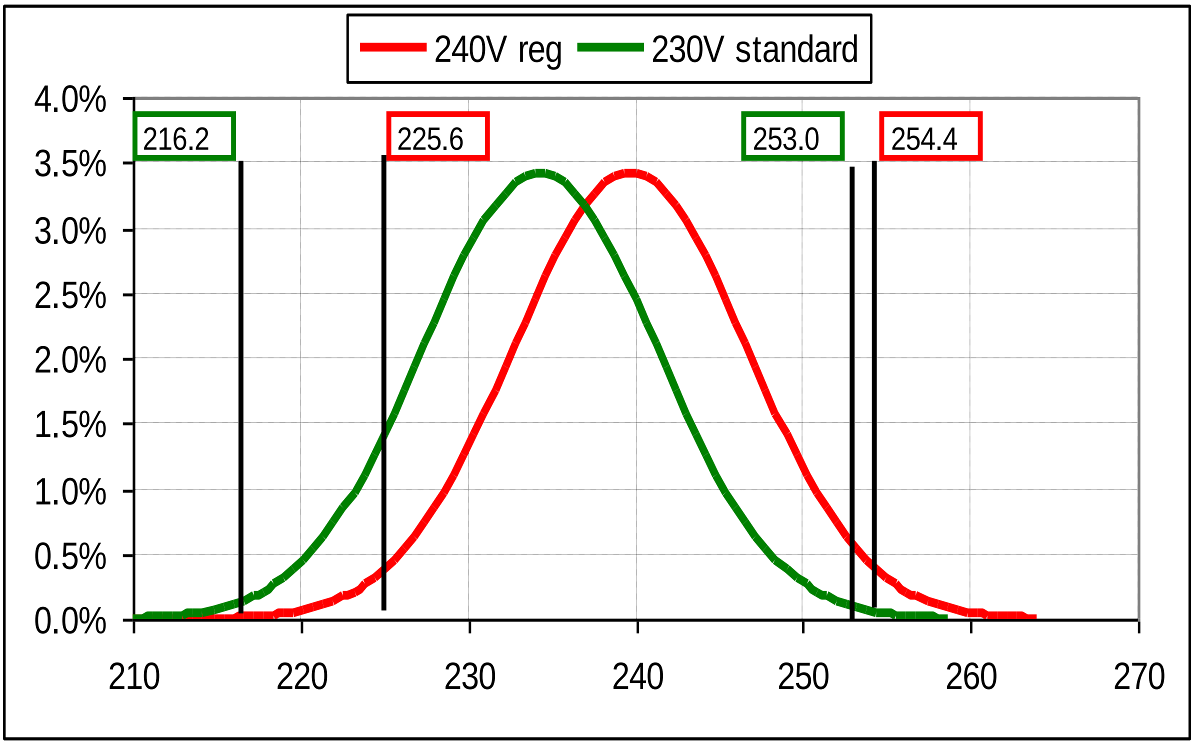


**Figure 25: 240V to 230V Standard Impact on Customer Voltage Probability Distribution**

With the additional 4% voltage allowance, Energex will have a voltage regulation range of around 16% compared to the existing 12%. This will enable Energex to selectively lower the voltage profile in impacted areas to maintain the voltage within the high voltage limit at light load conditions or times of peak solar PV generation. Whilst the upper supply limit of both standards is similar (253.0V versus the existing 254.4V), the lower end of the 230V standard is only 216.2V (versus the existing 225.6V). With the additional allowable voltage drop within customer's installations of 5% according to the Wiring Rules (AS3000), full implementation of the 230V standard will require careful consideration to ensure compatibility of any proposed voltage standard with customers' equipment.

Energex, in collaboration with Ergon Energy has developed a discussion paper which is examining the technical implications and impacts for the move to the 230V standard. A future transition plan is expected to require a combination of changes to distribution transformer tap settings and modification to the zone substation 11kV Line Drop Compensation (LDC) settings. With regards to customer appliances, the minimum utilisation voltage of 204.7V allowed under the 230V standard may not be adequate for some legacy 240V equipment such as motors.

Although Energex is investigating the introduction of the 230V standard, its introduction has not been factored into any specific programs, as its introduction is unlikely to be before the end of the next regulatory period.

### 5.2.2 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 voltage on the LV supply. On the customer side this includes

Australian Standard AS4777 compliant solar PV inverters with reactive control capability and power export limiting devices. The technology market will continue to be scanned and where economically and technically viable, be introduced as standard products.

#### 5.2.2.1 MicroPlanet

The “MicroPlanet” voltage regulator is a single phase 80 amp capacity regulator designed to smooth voltage fluctuations from nearby disturbing loads. It has been trialled by both Ergon and Energex, with application to avoid potentially costly network augmentation for the benefit of a few customers. The “Microplanet” device is installed on the low voltage pole (or pillar) supplying the customer. Energex installed around six devices, with two having failed and been replaced due to lightning damage. This device is mainly applied for limiting voltage disturbances (e.g. fluctuations) to small numbers of customers rather than steady state voltage management.

#### 5.2.2.2 StatComs

These are a shunt compensation device that are installed at a point along an LV circuit, usually at the point two thirds along its length. By carefully controlling the output, the units can be used to sink or source reactive power. Although reduced benefits are achieved in areas of low X/R ratios (e.g.. 95 mm2 ABC or 240 mm2 Al u/g), they appear to offer quick solutions to voltage problems in traditional bare conductor overhead networks. The addition of batteries offers the potential to increase the voltage management functionality by effectively reducing net load or net generation. Storage also offers the possibility of providing capacity benefits, albeit with the additional overhead of battery maintenance and replacement costs. In summary, there are four control options that can benefit the network:

During high voltage conditions (as might be experienced during light load and high PV)

- Sink real power by charging batteries; or
- Sink reactive power.

During low voltage conditions (as might be experienced with peak load)

- Source reactive power; or
- Source real power by discharging batteries.

#### 5.2.2.3 Distribution Transformer Automatic LV Regulators

This strategy moves the point of regulation from the substation or feeder to the distribution transformer. LV regulation can then be managed for the specific needs of the area by installation of automatic voltage regulators (AVRs) on the LV side of the distribution transformer. These devices dynamically adjust voltage for the distribution network to maintain voltage within defined limits at the transformer low voltage terminals. These devices would be required to accommodate and manage occurrences of reverse power flow into the network from solar PV customers.

#### 5.2.2.4 Customer Voltage Controlled Solar PV with / without Battery Storage

This strategy 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. Draft changes to Australian Standard AS4777 have introduced requirements and recommendations for these functions. Energex 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. It may also be a positive business case to change out a number of inverters in problem areas at Energex cost with the customer signing an agreement for Energex to control the inverter.

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. Further details can be referenced in the Demand Management Strategy (sect. 5.2).

## 5.3 Options Assessment

The program initiatives are based on the current regulatory requirement to maintain statutory voltages within the range 240 V ± 6% and will mainly address worst areas emerging from the growth of solar PV on the network. The introduction of the 230V Australian standard has been considered but is unlikely to lead to any cost savings this regulatory period. However its introduction should give greater flexibility to manage voltage and help to mitigate the growth in voltage related issues into the 2020-25 period and beyond.

To meet the future requirements, Energex has opted to build the CAPEX program using standard building block products rather than introduce new technology. This may change if any of the trials and evaluations proves a sound business case.

## 5.4 Program Initiatives

Program initiatives have been developed to support the Power Quality future requirements. In the case of the LV network, initiatives take into account network refurbishment and augmentation drivers and projects to improve efficiency and effectiveness. Operating initiatives include resetting distribution transformer taps and rebalancing the PV and load across phases. Capital initiatives include increasing the LV conductor size and reducing the lengths of LV circuits by installing additional distribution transformer injection points. A composite factor analysis approach is taken to carefully target solutions to high risk areas.

The programs proposed in the next regulatory period (2015-20) take account of the current funded activities in the 2010-15 regulatory period such as lowering voltage profiles at zone substations. The lowering of zone substation bus voltages by itself is considered a short term response and may lead to sub optimal outcomes in the long run due to reduced network capacity and increased losses. The programs proposed therefore take a long term view and will seek to optimise the voltage profiles in conjunction with distribution transformer tap settings and other initiatives. A review of the substation Line Drop Compensation (LDC) and distribution transformer tap setting policy is underway and will be used as the basis for any future changes in the 2015-20 regulatory period.

### 5.4.1 Voltage Monitoring & Reporting

Due to the complexity of the network and the large number of sites involved, the management of voltage presents many challenges. To address these challenges the systematic approach shown in Figure 26 is being adopted. This involves:

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

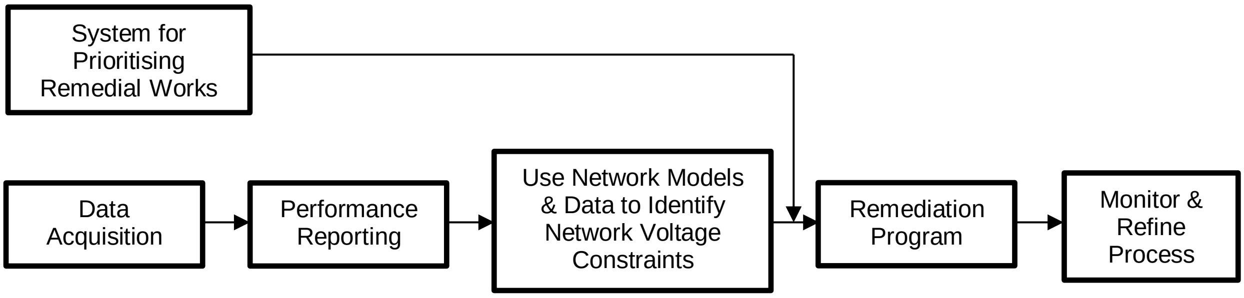


**Figure 26: Systematic Approach to Voltage Management**

#### 5.4.1.1 Retrofit Zone Substation Monitoring

This strategy addresses the need to capture power quality monitoring parameters at each of Energex's zone substations and will support DAPR reporting as well as analytics to improve voltage management. The PQ smart meters have capability to capture steady state voltage, voltage harmonics, voltage unbalance and voltage sags. The program received funding in the 2010-15 regulatory period and is expected to be complete by the end of 2014/15. All new zone substations should continue to include a PQ monitor as part of the standard building block.

#### 5.4.1.2 Retrofit Distribution Pole Transformer Monitoring

The retrofit of smart meters to distribution pole transformers commenced in the 2010-15 regulatory period to remotely read voltage and demand measurements and replace Maximum Demand Indicators (MDI's) on transformers 100 kVA and above. The majority of sites have been installed in combination with the LV fusing safety program to ensure program efficiencies. Additional monitoring sites are also selected at the end of 11kV feeders to monitor expected worst case voltage at the transformer terminals, as part of the PQ monitoring strategy. In the 2015-20 period, further sites will be installed under the LV fusing program and at the end of 11kV feeders. By 2019/20, it is expected that most pole transformers 100 kVA and above will have monitoring installed and monitoring installed on the majority of single phase and three phase transformers less than 100 kVA at the end of 11kV feeders. This comprehensive coverage will support DAPR reporting as well as analytics to improve voltage management.

### 5.4.1.3 Retrofit Distribution Padmount Transformer Monitoring

The retrofit padmount transformer monitoring program using smart meters to remotely read voltage and demand measurements and replace Maximum Demand Indicators (MDI's) is expected to commence in the 2015-20 regulatory period. The sites will also be chosen at the end of 11kV feeders to monitor expected worst case voltage at the transformer terminals, as part of the PQ monitoring strategy. Sites will also be chosen in older residential areas where infill development is expected to result in higher demand growth and in high PV penetration areas. This comprehensive coverage will support DAPR reporting as well as analytics to improve voltage management.

### 5.4.1.4 LV Circuit Monitoring

This strategy aims to gain greater knowledge and insight into the voltage being experienced as close as possible to customer terminals to improve voltage management decision making. As already discussed, the influence of solar PV on the Energex network is likely to cause some parts of the network to exceed the statutory voltage limits. Targeted voltage monitoring at the end of a sample of overhead LV circuits in conjunction with monitoring at the distribution transformer will provide further information on which to base credible network solutions across the network, as well as monitoring the effectiveness of these solutions. Reconfiguration of LV circuits will occur and will need to be factored into the data collection and management systems. There will also be a need to periodically recover and shift monitoring points that become redundant.

### 5.4.1.5 LV Customer Monitoring

This strategy aims to gain greater knowledge and insight into the voltage being experienced at customer terminals in targeted areas to improve voltage management decision making. At least initially, it is proposed to achieve this by targeting areas of the network most likely to have issues and change out of existing meters at sites likely to represent the control point or design limit. This approach has the potential to provide a low cost solution to voltage monitoring across the network with minimal additional effort.

In most cases the meters will be installed in customer premises at the end of the LV circuit, but the choice may be affected by the length of circuit, the loading and amount of solar PV. In residential areas the aim will be to maintain the status of the meter site as 'read only' while providing capability to remotely read and store 10 minute average voltage data in the Energex metering "head-end" and ultimately monitoring data warehouse.

Due to the fact that the majority of residential customer installations are single phase, three customer sites per LV circuit would need to be scoped to obtain all three phase voltages. This adds some complication to the process and increases the number of meters.

As for the LV circuit monitoring proposal, reconfiguration of LV circuits will occur and will need to be factored into the data collection and management systems. This may make monitored sites redundant as a control point site and may trigger some churn.

#### 5.4.1.6 Neutral / Phase Integrity Monitoring

This strategy aims to address community safety by providing 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. Energex’s five year system based maintenance inspection program identifies obvious neutral issues, but is not sophisticated enough to detect intermittent or incipient problems.

This capability will require the utilisation of distribution monitoring and analytics to better quantify issues and target resources. The basis on of the techniques have been implemented in Victorian Distributor SPAusNet, who have detected incident rates of 1 in 3000 consumers at risk in their distribution area using smart meter data. Deployment will be targeted based on historical reported failures to classify environmental factors that provide the highest risk areas.

Other benefits of the strategy include:

- Extreme voltage avoidance where the electricity meter deployed isolates the customer if an event occurs to prevent house fires or damaged appliances (events like HV to LV contact can be mitigated at the consumers connection point).
- Solar compliance detection where the detection of incorrectly set inverters contribute to network voltage issues. This could also be enhanced to a solar enforcement program to disconnect customers with inverters that are not corrected.
- Reduced meter reading and meter management costs.
- Support for new tariffs including potential KW and KVA tariffs.
- Remote disconnects and arm for reconnect cost reduction.
- Loss of phase and restoration of supply alarms.

The strategy will initially target areas of the network where historical evidence indicates best value can be achieved. Preliminary research is pointing towards coastal areas where corrosion is a problem.

### 5.4.2 Field Data Capture

This strategy supports a review of existing voltage management criteria by addressing the lack of robust data recording the position of distribution transformer tap positions and tapping plans. As indicated in the issues section of this paper, incorrect setting of distribution transformer tap settings may be contributing to voltage issues. A program to collect and record this data is proposed in the 2010-15 regulatory period by 2014/15 which will support the proposed area by area reviews of tapping plans in high risk areas.

### 5.4.3 Voltage Investigations

Figure 27 shows the generalised variation of steady state voltage at customer sites across the network assuming a ‘normal’ probability distribution. The red curve illustrates possible remedial strategies to reduce high voltage and the green curve remedial strategies to reduce low voltage.

High and low voltages need to be addressed in a prioritised and systematic manner as well as ensuring the overall voltage management objectives are optimised to maintain voltage within the current 12% 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 penetration threshold of around 40% will be targeted. It is however acknowledged that growth in solar PV over the regulatory period may significantly increase the number of transformers with 40% penetration.

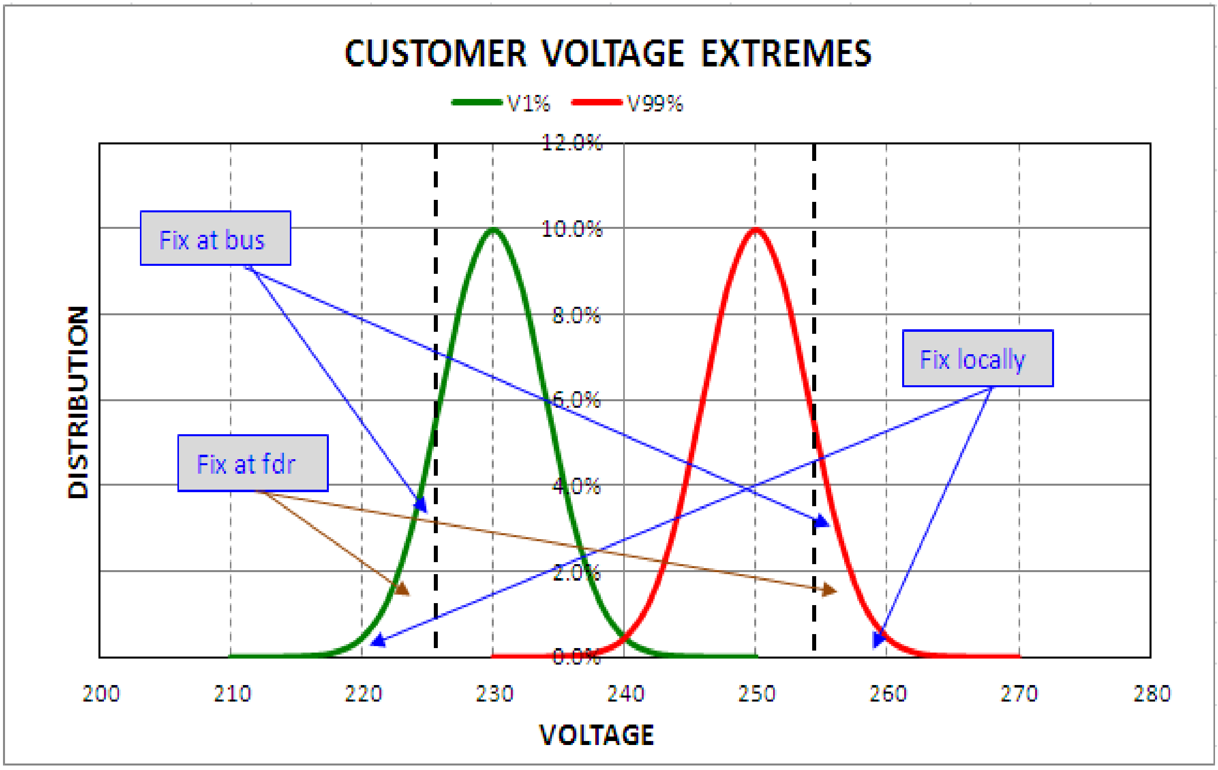


**Figure 27: Distribution Transformer / Customer Voltage Variation**

The PQ initiatives are categorised according to the manner in which they are activated or managed. Some initiatives will be effectively driven as programmed works designed to systematically improve the network form the top down. Broad based HV initiatives are an obvious example. By contrast, other local HV or LV initiatives would not be conducted in a systematic manner throughout the network but would be initiated in response to a particular problem identified through data acquisition or customer complaint.

The investigation process for voltage outside limits or high PV penetration generally consists of the following steps:

1. Check system normal
2. Check 11kV bus voltage
3. Check 11kV Automated Voltage Regulator (AVR) settings
4. Check 11kV voltage drop
5. Check Distribution transformer tap

6. Check PV on LV
7. Check LV voltage drop / rise
8. Check LV load / PV balance

The outcome of these steps will generally determine the type of network solutions that may be required.

### 5.4.4 Network Solutions

The engineering investigations will drive the development and refinement of remediation OPEX and CAPEX programs. This section outlines the key elements of each.

#### 5.4.4.1 LV Distribution Lines – 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. This is clearly illustrated in Figure 28. It shows the voltage variation at a customer site towards the end of an LV circuit in a semi-rural residential area with high solar PV penetration exceeding 40%. ‘A’ phase is high during daylight hours when solar generation is on and ‘A’ phase is low during peak load times when solar generation is off.

Figure 29 shows the same one week sample of data plotted as a voltage frequency distribution. This type of analysis is very useful as it more readily shows the pronounced voltage unbalance between phases and the degree of spread of voltage with respect to the limits.

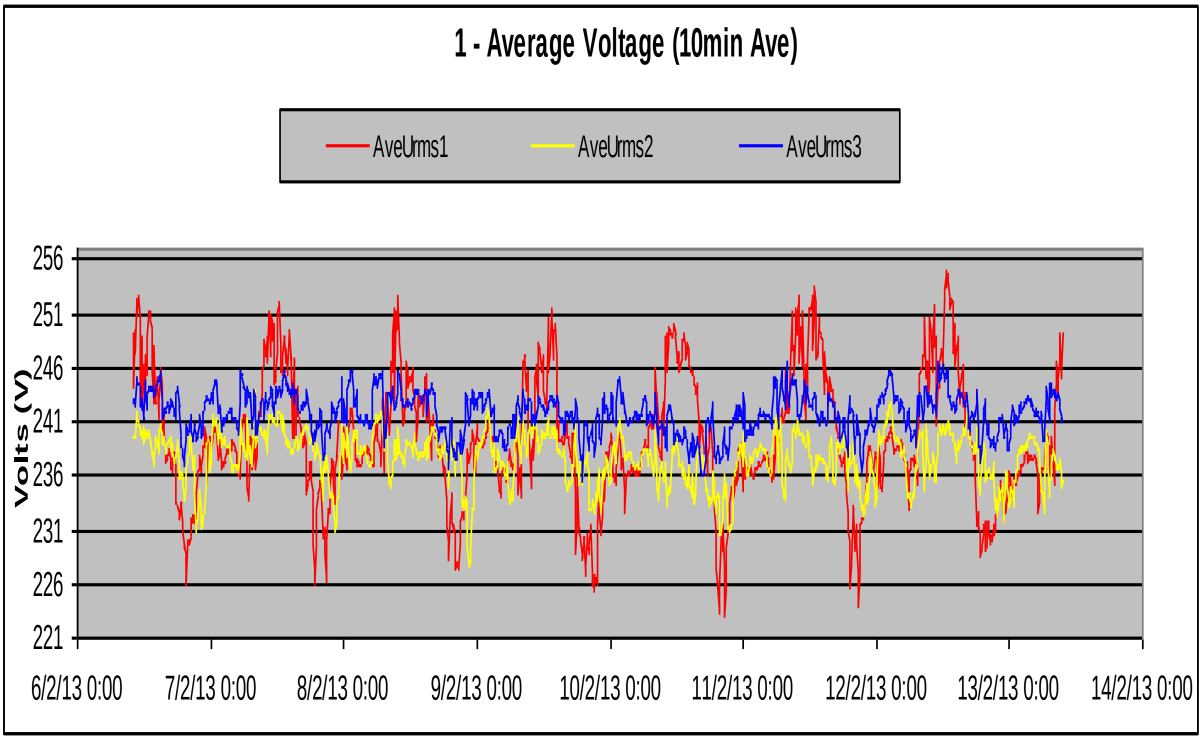


**Figure 28: LV Circuit Voltage Monitoring Site Ward Street, Morayfield**

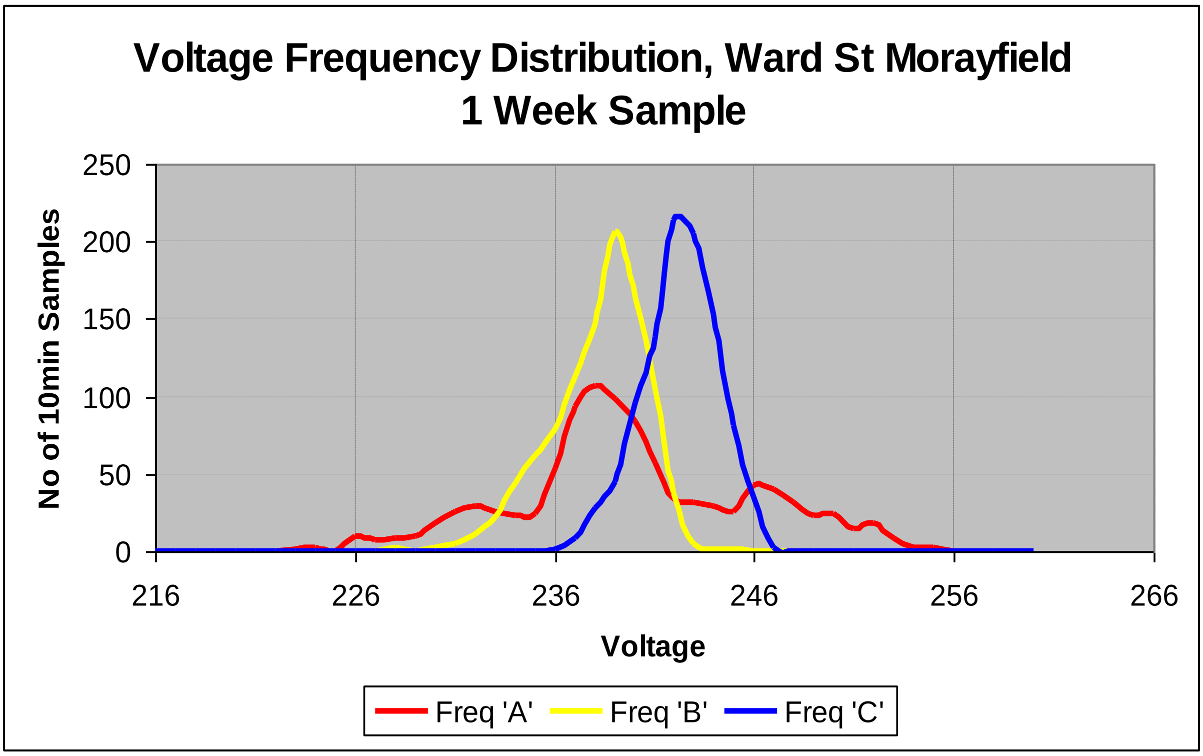


**Figure 29: Voltage Frequency Distribution, Site Ward Street, Morayfield**

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

#### 5.4.4.2 LV Network Upgrades

There are two conventional network solutions able to most effectively address the voltage regulation on the LV network:

- Replacing smaller cross-sectional area LV circuit mains (e.g. 7/.080 & 7/.064 Cu) and / or service conductors to customers
- Reducing excessive lengths of LV circuit mains (greater than 400m initially) by installing additional distribution transformer injection points and reconfiguring LV open points.

Both of the preferred solutions work by reducing the network impedance to the customer point of connection but have the advantage of providing additional benefits for the network in terms of reliability, safety and capacity improvements. A third solution to uprate the distribution transformer capacity is not preferred, as it only reduces the voltage regulation through the transformer and not the LV circuit.

#### 5.4.4.3 Review and Adjust Distribution Transformer Tapping Profiles

Energex is reviewing the philosophy behind setting distribution transformer tapping plans. A possible strategy is to change the selection from peak load voltage drop to no load terminal voltage limited by the high voltage statutory limit of 254.4 volts. Figure 30 demonstrates this by displaying the calculated no load LV terminal voltages of distribution transformers that takes into consideration any substation Line Drop Compensation (LDC) settings and the light load condition.

It shows transformers before the LDC crossover will experience maximum primary (11kV) voltage typically at periods of high load and those after the crossover will experience maximum primary voltage at periods of light load. The latter effect requires a lowering of transformer taps at feeder extremities to avoid over-voltages. This change in philosophy mainly affects transformers below the 5% voltage drop position which are set to Tap 5/7 instead of 6/7.

This shows that the overvoltage at the feeder extremity is consequently eliminated. The changed tap settings do however expose sites towards the end of the feeder to potentially low voltage as defined by the 242V minimum terminal voltage under full load (Section 3.3.3 of Supply & Planning Manual). Unlike the high voltage problems, there are simple remedies to this in the design stage, in the form of shorter LV, lower impedance LV mains or in some cases large capacity distribution transformers. The argument that the 50 PoE and 10 PoE load with its associated minimum voltage occurs far less frequently than the nightly light load scenario supports the proposed tap plan, but will not obviate the obligations to maintain statutory voltage under such peak load conditions when they do occur.

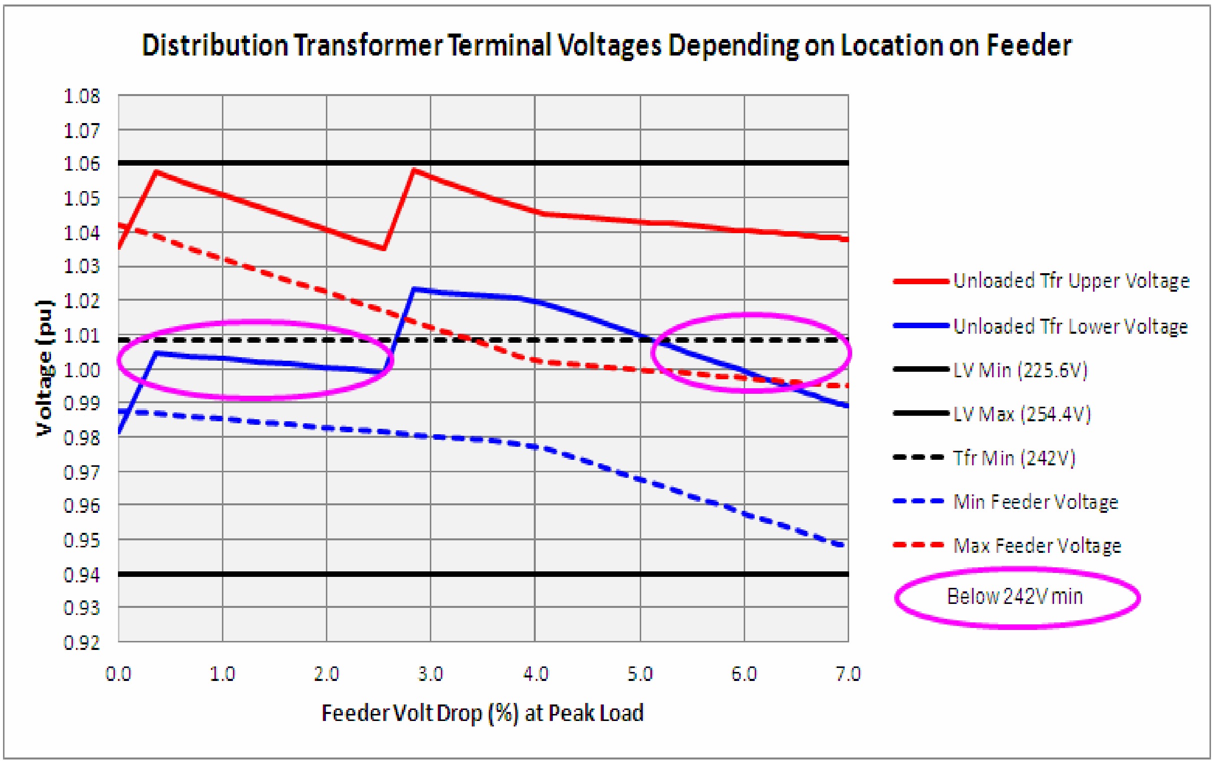


**Figure 30: Unloaded Transformer Secondary Voltages along the Feeder with 3% LDC, 7% VD, 2.45% BW, Taps 3, 4 & 5 on 7 Step 2.5% Tap Transformers**

### 5.4.5 Summary

To address the key drivers, seven capital program initiatives are proposed as shown in Table 4. Some of the initiatives are a continuation or expansion of existing programs and some are new, being required to address the emerging issues. This capital program will be supported by operating initiatives that include company initiated investigations addressing solar issues, rebalancing of the LV phase connections and resetting of distribution transformer taps.

**Table 4: Summary of PQ 2015-20 CAPEX Initiatives**

| Ref # | Initiative Title | 2010-15 Current units | 2015-20 Proposed units | NAMP | Years | Spend Cat |
|---|---|---|---|---|---|---|
| **Monitoring / Reporting & Data Analytics** | | | | | | |
| PQ1A | Distribution Transformer monitoring (<100kVA) - Pole | 270 | 1,854 | CA15 | 5 | C25 |
| PQ1B[1] | Distribution Transformer monitoring (≥ 100kVA) - Pole | 3,530 | 6,865 | CA17 | 3 | C25 |
| PQ2 | Distribution Transformer monitoring - Padmount | 520 | 1,750 | CA44 | 5 | C25 |
| PQ3 | LV Circuit monitoring | Nil | 1,800 | CA48 | 5 | C25 |
| PQ4 | Customer monitoring | Nil | 4,200 | CA48 | 5 | C25 |
| PQ5 | Neutral Integrity Monitoring | Nil | 28,050 | CA50 | 5 | C25 |
| **Rectification Works** | | | | | | |
| PQ6A | Uprate & Reconfigure LV Network (OH) | Nil | 720 | CA46 | 5 | C25 |
| PQ6B | Uprate & Reconfigure LV Network (UG) | Nil | 120 | CA46 | 5 | C25 |
| PQ7[2] | Reconductor mains with LVABC (Fault level and PQ program) | 500km | 660km | CA08 | 5 | C25 |

Note:

1. Initiative PQ2 meter component is part of an LV fuse installation program.
2. Initiative PQ7 is part of a reconductoring refurbishment program.

# 6 Governance & Review

## 6.1 Ownership

This strategy is owned by Group Manager Network Maintenance & Performance within the Asset Management Division.

## 6.2 Governance

Energex Program of Work Governance shown in Figure 31 ensures strategy & policy development and resulting portfolio investment approvals align to achieve the strategic objectives of the business. Monitoring and review of the program of work performance against annual targets and performance standards is undertaken by the Network Operations & Steering Committee.

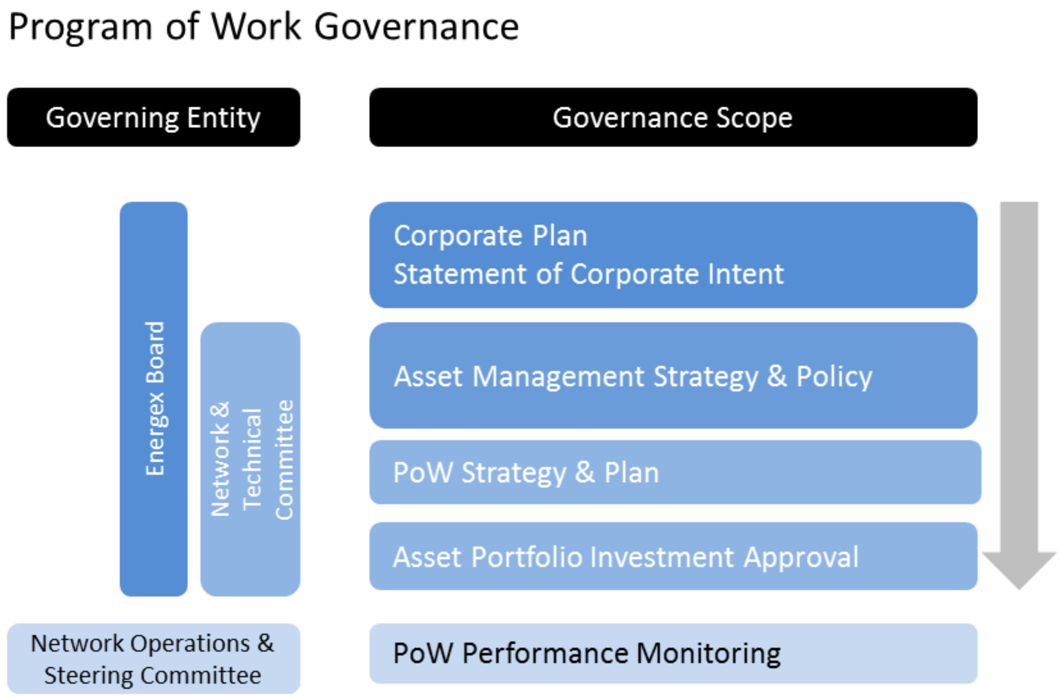


**Figure 31: Program of Work Governance Framework**

## 6.3 Performance Monitoring and Reporting

Monitoring of performance achieved compared to the approved program investment is to be presented on an annual basis to the Network Operations and Steering Committee or earlier if as requested.

Reporting about this strategy/program is facilitated through the following form/methods:

- Power Quality Annual Report

Reporting occurs at annual intervals and is produced by the Network Maintenance & Performance Group.

## 6.4 Review

This Strategic Plan is to be reviewed annually as part of Energex's annual business planning process. Review details can be referenced in the Version Control section at the start of this document.

## 6.5 Publication

The current version of this Strategic Plan is available on the Energex Intranet and can be accessed via the *Reliability & Power Quality* Intranet page.  All other electronic and printed versions of this document are to be deemed as non-current and uncontrolled unless specifically authorised by the owning Group Manager.