

APPENDIX 4.8

Energex revised power quality program

Energex

Power Quality Augex Forecast
Revised Regulatory Proposal

Asset Management Division



positive energy

Energex

Power Quality Augex Forecast 2015/16 - 2019/20

Reviewed:

 1/7/15

Ron Barbagallo

Group Manager Network Capital Strategy & Planning

Endorsed:



Peter Price

Executive General Manager Asset Management

Version control

Version	Date	Description
1	23/06/15	For submission with revised regulatory proposal

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.

© Energex Limited, Australia

This work is copyright. Material contained in this document may be reproduced for personal, in-house or non-commercial use, without formal permission or charge, provided there is due acknowledgment of Energex Limited as the source.

Requests and enquiries concerning reproduction and rights for a purpose other than personal, in-house or non-commercial use should be addressed to:

Group Manager
Corporate Communications
Energex
GPO Box 1461
BRISBANE QLD 4001

Executive Summary

Energex's regulatory proposal included a program targeted at monitoring and managing power quality issues and in particular the issues resulting from the high penetration of solar PV connected to the LV network. Energex's power quality strategic plan was provided as an Appendix to Energex's regulatory proposal.

Traditionally, distribution networks were designed to accommodate the flow of power in one direction from the substations through to the customer. Basic maximum demand indicators were relied upon to identify limitations on distribution transformers. The growth in solar PV and the increasing levels of reverse power flows between the LV and 11 kV networks means that more sophisticated transformer monitoring is required.

The unprecedented uptake of solar over the last five years has resulted in Energex having one of the highest per-capita capacity of rooftop solar PV in the world. Such a significant change introduces a set of new challenges to operate the network in a safe, reliable and economically efficient manner. This phenomenal uptake rate has exceeded all expectations, driven by a combination of Federal and State incentives, rapidly falling PV technology costs and steeply rising electricity prices.

Aurecon has independently analysed comparative solar PV data for a selection of Australian Utilities as at 30 June 2014. Aurecon found that Energex is experiencing penetration of solar PV installations per LV area (per distribution transformer) that exceed those experienced by other utilities by a factor of between 2 and 8 times. Also that only a very small number of utilities worldwide (in the USA and Germany) have a higher solar PV penetration when the impact on low voltage networks is considered. Aurecon concluded that Energex's situation (in terms of impact) is difficult to compare with other utilities, and results in the need to implement measures that are not comparable to practices adopted by other utilities. As a result, *"Energex is likely to require significantly greater levels of monitoring and remediation than any other Utility in Australia."*

In its preliminary decision the AER has raised a number of issues relating to Energex's proposal. Energex has noted the areas of concern and believes they are addressed in this revised proposal.

On this basis, Energex does not propose any change to its original proposal.

\$m, 2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	Total
Energex original proposal	5.8	4.9	4.9	11.4	11.5	38.4
AER preliminary decision	3.6	3.1	3.1	7.1	7.2	24.0
Energex revised proposal	5.8	4.9	4.9	11.4	11.5	38.4

The key issues raised by the AER are addressed further:

Solar PV Forecast

The AER raised concerns that the projected increase in solar PV connections is likely overstated because it does not account for the expected softening of solar growth. Energex has reviewed the basis for the forecast and found it to be well supported by the PV market fundamentals. Although the revised forecast does not materially alter the number of new connections over the five year period it

does account for the increase seen in the average size of inverters from around 3 to 4kVA. This increase in average size is expected to be sustained into the future, resulting in an overall capacity on the Energex network by 2020 of around 1,518 MVA. This is more than 10% above the original capacity figure of 1,352 MVA (refer Table 3).

Based on Energex's modelling assumptions, the increase in installed inverter capacity will increase the number of areas on the network above the threshold expected to cause voltage issues for customers. Given forecasting tolerances and the fact that Energex did not allow for an increase in the average inverter size in the submission, Energex will manage this increased risk with no further increase to the original proposed expenditure.

In March 2015 the Queensland Government announced a target of one million solar PV rooftops by 2020. Whilst the details of how this might be achieved are still unknown, it is likely to result in an increase in the levels of connected solar PV. Given consultation is still ongoing and the final form of the targets is uncertain, no allowance has been made in Energex's revised solar PV connections forecast at this time. However it is likely that additional inverter capacity will be connected to the network in the future that is not currently accounted for in Energex's revised forecast. This represents a risk to Energex.

Energex's response to the statement that they "expect Energex will take AEMO's latest forecast into account when preparing its revised proposal" is:

A comparison of the Energex and AEMO updated June 2015 forecasts shows that their forecast for energy generated is significantly higher than Energex's solar PV generation forecast. This would indicate that Energex's forecast may understate rather than overstate growth in solar PV. [Energex Solar PV Connections Forecast, Appendix 4.9]

Monitoring & Remediation

Energex's response to the statement that "Energex's proposed level of network monitoring is above the level of power quality monitoring present at most network operators". is:

Unlike distribution network service providers in New South Wales and Victoria, communication enabled meters are not installed at domestic customer premises to access network data for analysis purposes in Queensland. In addition, the take-up of solar PV in South East Queensland is substantially greater than other states. The forecast of new solar PV connections together with the Qld Government aspirational target of 1 million solar PV rooftop connections in Qld by 2020 further supports the need for the proposed level of monitoring.

The main strategy and imperatives for the LV monitoring and remediation program is to address community safety risks and meet legislative compliance.

A safety risk assessment for the high penetration of solar PV assessed the risk as Medium Risk. This was based on a worst case safety risk scenario for high solar PV penetration of a high voltage (above 260 V) at a premise causing equipment/appliance fire, leading to houses catching fire and multiple fatalities.

Energex then considered control measures in a two-step approach to manage the Medium Risk to As Low As Reasonably Practical (ALARP). LV monitoring and neutral integrity monitoring were shown to reduce the risk score to a Low to Medium risk. The distribution transformer re-setting program was considered separately because it is a long term solution which will take over 10 years to implement.

The risk score for the tap resetting program along with the LV and neutral integrity monitoring implemented came to low risk and ALARP.

Energex has obligations to maintain the low voltage at customer terminals of $240V \pm 6\%$ (225.6V to 254.4V). Energex typically sets its transformer taps in the range of 242 V to 250 V in order to allow for voltage drop caused by peak load. The scope for voltage rise is in the range of 2% (5V) to 5% (12 V) before regulated high voltage limits are reached. Generally networks can only tolerate solar PV penetration levels up to 30% and stay within the maximum voltage. With 100-150 transformers reaching this threshold each month, the challenges are increasing rather than reducing.

Although penetration levels above 30% are expected to cause problems, Energex has set its Augex remediation program at a level above this in recognition that a range of OPEX solutions will be in place to manage more moderate safety and legislative compliance issues. The level was set at 40% penetration and excessive LV circuit lengths greater than 600 metres. LV circuit lengths to the furthest customers are generally considered excessive for lengths exceeding 400m in overhead networks.

The LV monitoring program will also be beneficial in reducing future OPEX and CAPEX expenditures to an estimated \$1 Million p.a. This percentage saving of around 25% p.a. will provide a payback period of around five years (initially). These benefits are outlined below:

- Energex currently undertakes 100 voltage investigations per month under an OPEX program with an average investigation time of 14 hours. Of these investigations, 40% are related to solar PV and require a formal voltage investigation with monitoring equipment installed. The installation of LV monitoring is expected to reduce the investigation time by around 3 hours (removes the need to install the PQ equipment) at a cost saving of \$720 per investigation. The expected OPEX savings are \$350,000 p.a (40 investigations x 12 months x \$720 saving). In addition, power quality monitoring will allow power quality issues to be identified and rectified before the community and customers are put at risk.
- A pilot CAPEX project was undertaken to determine the cost of capital remediation works in one of Energex asset areas. The remediation costs range from \$24,000 to \$170,000 with the average of \$65,000. The budgeted expenditure on the remedial program is \$11 Million p.a. under the customer initiated distribution Augex allowance. The LV circuit monitoring program will be installed on around 60% of the transformers with PV penetration >25% and around 20% of the number of LV circuits off these transformers. The savings due to the LV monitoring program are expected to be in the range 6-8% of the remedial program based on better information and decision making, leading to efficiencies and tighter control over the scope of works. With a budgeted remedial program cost of \$11 Million p.a. the lower range is expected to result in a saving of \$660,000 per annum.

Aurecon has separately considered Energex's proposed monitoring program. It concluded that it is essential to establish a monitoring program to gather data required to clearly identify the extent of network problems, and to use as input to modelling the network and testing possible remediation measures. Further, that reducing the number of monitors proposed would result in insufficient accuracy for the results to be effective in gaining a deep understanding of the impact of solar PV penetration, and would also result in potentially ineffective or unnecessarily costly mitigation strategies being employed.

Aurecon also reviewed Energex's proposed capital expenditure on remediation works. They considered Energex cost allowance to be at the lower end of their estimated range of expected

outcomes and could result in Energex having to manage a higher network risk associated with the impact of solar PV penetration.

In summary, the proposed Augex spend is justified based on:

1. The current level of solar PV penetration on Energex's network already identified as causing power quality issues with increasing number of customer complaints.
2. The forecast increase in the connected inverter capacity on the network over the next five years will rapidly increase the number of distribution transformer areas expected to have power quality problems.
3. Energex forecast of new solar PV capacity is substantially below that forecast by AEMO, reinforcing that Energex's view of continuing growth in connections is reasonable and supported by market fundamentals.
4. Potential increase in forecast solar PV connections due to Qld Governments stated aspirational targets for 1 million solar PV rooftops in Qld by 2020 is not factored in and presents a further network risk that will need to be managed by Energex.
5. Energex does not have any substantial penetration of remotely read electronic capable meters at customer premises to monitor power quality as in southern states.
6. The take-up of solar PV is substantially greater in South East Queensland than in southern states and as a result the requirement to monitor power quality is commensurately greater.
7. The level of Augex spend on monitoring and remediation works is well targeted to areas expected to be impacted on the basis of measurements and modelling and will produce financial savings that would otherwise result in further increases in reactive expenditures.

Contents

1	Introduction.....	1
2	Challenges	1
3	Proposal	2
4	AER Key Issues	2
5	Solar PV Forecast	3
6	LV Monitoring Business Case	5
	6.1 Other Distributors	5
	6.2 Drivers.....	5
	6.3 Prudency in Capex Expenditure.....	6
	6.3.1 Scale & Scope.....	6
	6.3.2 Options for LV Management.....	8
	6.3.3 Risk Assessment.....	9
	6.4 Financial Benefits Analysis	10
	6.5 Conclusions	12
7	Remediation Business Case.....	12
	7.1 Prudency in Capex Expenditure.....	12
	7.1.1 Scale and Scope.....	12
	7.1.2 Options (Network)	14
	7.1.3 Options (Customer).....	16
	7.2 Risk Assessment	17
	7.3 Conclusions	17
8	Other Factors	17
	8.1 230V Standard	17
	8.2 Connections Policy.....	18
9	Revised Proposal.....	19
	APPENDIX A: LV Monitoring Savings	20
	A1 OPEX savings	20
	A1.1 Voltage Investigations	20
	A2.2 High Voltage Incidents leading to Equipment Damage and Insurance Claims....	21
	A2 CAPEX savings.....	24

APPENDIX B: Voltage Rise on LV Networks26

APPENDIX C: New Connections Assessment Process30

1 Introduction

The report outlines Energex’s revised power quality proposal with supporting justifications addressing the key issues raised by the AER.

2 Challenges

Energex’s original regulatory proposal for power quality was based on the significant challenges in managing network voltage through the unprecedented growth in residential rooftop solar PV in south east Queensland. Although this has been discussed extensively in Energex’s power quality strategic plan, its significance is not well understood by all stakeholders as voltage quality does not have the same transparency as reliability of supply (ie “keeping the lights on” is easily measured and experienced).

To put this into context, the installed capacity in Queensland now exceeds 1,300 MW and for comparison is approaching half of that installed in US State of California (population of 39 million), known for its “green” policies. With south east Queensland already contributing close to 1,000 MW, this makes Energex a world leader in terms of customer penetration with more than one in every four customers having PV systems on their premises.

Figure 1 provides a further world comparison showing the total installation capacity of solar PV in Australia and countries with high penetration of solar PV. It can be seen that Germany is by far the leader in solar PV uptake. After Germany, South Australia and Queensland have the highest solar rooftop PV generation per capita in the world. Energex installed capacity per capita of approximately 300 MW/Million population ranked no 3 in the world.

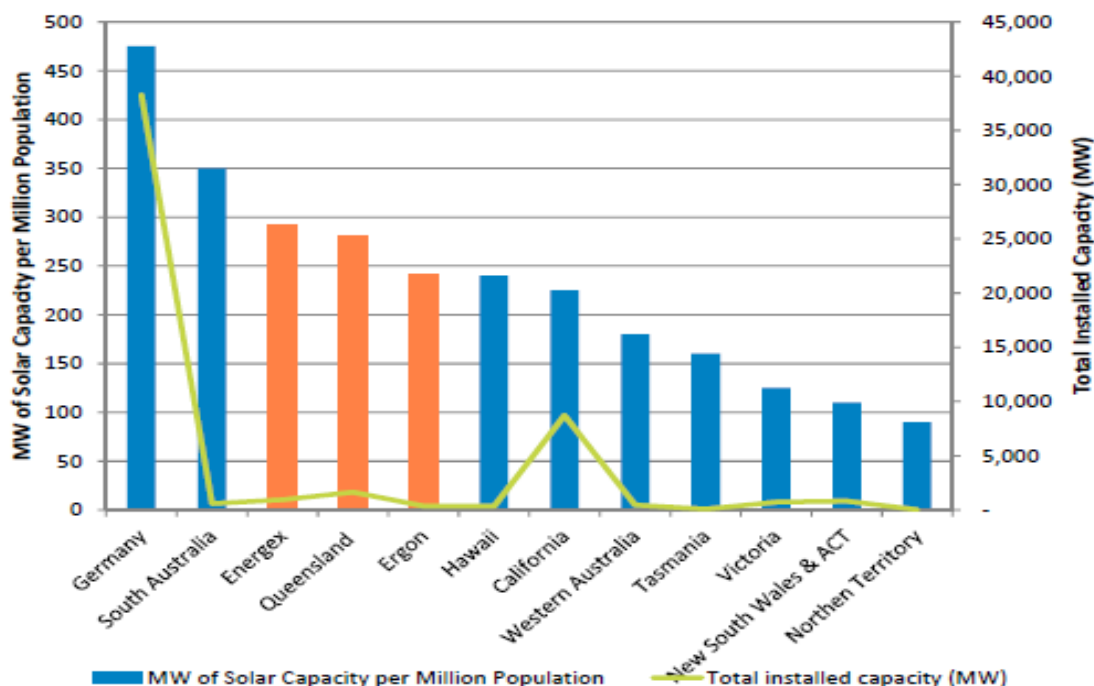


Figure 1: Total solar PV installation capacity and per capita

Energex identifies network issues to be managed on a local area basis for the low voltage network directly supplying customers. To do this Energex calculates solar PV penetration for each distribution transformer (which typically supplies 30 to 150 customers), which is the ratio of the kW of installed inverter capacity to the transformer capacity supplying the low voltage areas in question.

Aurecon has independently analysed comparative solar PV data for a selection of Australian Utilities as at 30 June 2014. Aurecon found that Energex is experiencing penetration of Solar PV installations per LV area (per transformer) that exceed those experienced by other utilities by a factor of between 2 and 8 times. Also that only a very small number of utilities worldwide (in the USA and Germany) have a higher solar PV penetration when the impact on low voltage networks is considered. Aurecon concluded that Energex’s situation (in terms of impact) is difficult to compare with other utilities, and results in the need to implement measures that are not comparable to practices adopted by other utilities. *“Energex is likely to require significantly greater levels of monitoring and remediation than any other Utility in Australia.”*

3 Proposal

Table 1 provides a breakdown of the power quality capital forecast from Energex’s regulatory proposal. This shows that around two thirds of the expenditure is on LV monitoring and the remaining third on LV remediation works. Table 2 provides a further breakdown of the monitoring spend with just over two thirds associated with continuation of existing monitoring programs at distribution transformer LV terminals and the remaining third with new programs to monitor at the end of LV circuits.

Table 1: Breakdown of Power Quality Capex Forecast

\$m, 2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	Total
LV Monitoring	3.8	3.2	3.2	7.4	7.5	25.0
LV Remediation	2.0	1.7	1.7	4.0	4.0	13.4
Energex proposal	5.8	4.9	4.9	11.4	11.5	38.4

Table 2: Breakdown of Power Quality Monitoring Capex Forecast

\$m, 2014-15	No Units	Total
Distribution Transformer (<i>existing</i>)	3,600	17.5
LV Circuit (<i>new</i>)	1,800	7.0
LV Customer (<i>new</i>)	4,200	0.5

4 AER Key Issues

The AER has reduced Energex’s proposed Augex for power quality on the stated basis that it has not sufficiently justified its programs with a risk and cost/benefit analysis which establishes the benefit of the programs. Specifically, engineering consultants EMCa found that (a) the proposed is above the level of power quality monitoring present at most network operators; and (b) the proposed PV remediation is not supported by robust analysis.

The AER considers that Energex’s projected increase in solar panel connections is not supported by any evidence that Energex relied upon (e.g. forecast models for growth in solar connections). On this basis the AER believes that the projected increase in solar connections is likely overstated because it does not account for the expected softening of solar growth.

Based on EMCa's findings and the uncertainty about the projected increases in solar connections over 2015–20, the AER has applied a 37.5 per cent reduction to Energex's power quality forecast (which is the mid-point of EMCa's recommended range). The AER consider that the mid-point is reasonable in the absence of evidence pointing towards to the top or bottom of the range.

5 Solar PV Forecast

Energex has prepared a revised Solar PV connections and inverter capacity forecast considering the AEMO forecast and Energex’s own supporting research of PV market fundamentals. Details of this forecast are contained in Appendix 4.9, Energex Solar PV Connections Forecast. The revised forecast with a comparison to the original is provided in Table 3.

In March 2015 the Queensland Government announced a target of one million solar roof tops by 2020. Given consultation is still ongoing and the final form of the targets is uncertain, no allowance has been made in Energex’s revised solar PV connections forecast at this time. However all indications show that the Government is actively pursuing its solar policy agenda, and that this will result in an increase in the levels of connected solar PV over what Energex is currently forecasting.

Figure 2 shows the percentage of domestic solar inverter capacities during 2010-2015 (to the end of March 2015). There is a clear trend towards the larger size systems (>3.5 kW) since 2011 as they becomes more economically attractive.

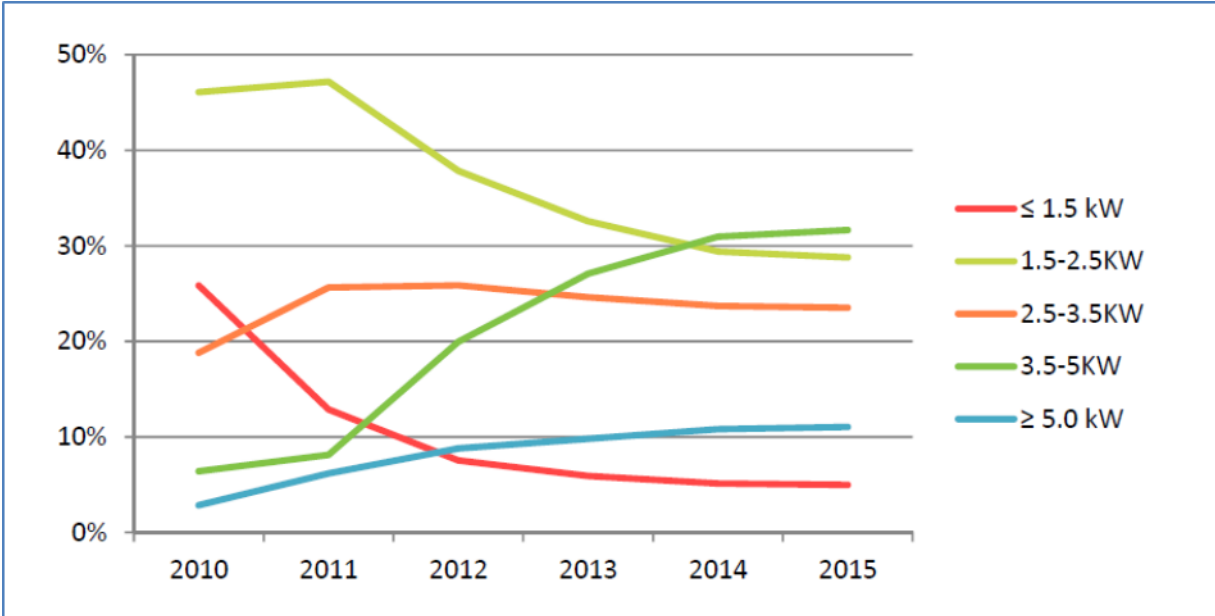


Figure 2: Installed domestic solar rooftop PV system size during 2010-2015

Energex’s original forecast was based on 30,000 new connections p.a. (2,500 per month) continuing for the first three years, tapering down to 20,000 in the fourth year and 15,000 in the fifth year (1,250 connections per month). The capacity forecast was based on an average inverter capacity of around 3 kVA. Although the revised forecast for the total number of new connections by the fifth year is not

materially different, the original capacity forecast did not account for growth in average size of installations indicated by Figure 2. To understand this trend further, Figure 3 shows the monthly average size of solar PV rooftop inverters for the same period. This clearly shows that new connections now average at just over 4kVA. When this is factored into the revised forecast, the installed capacity by 2010 is around 12% higher than the original forecast.

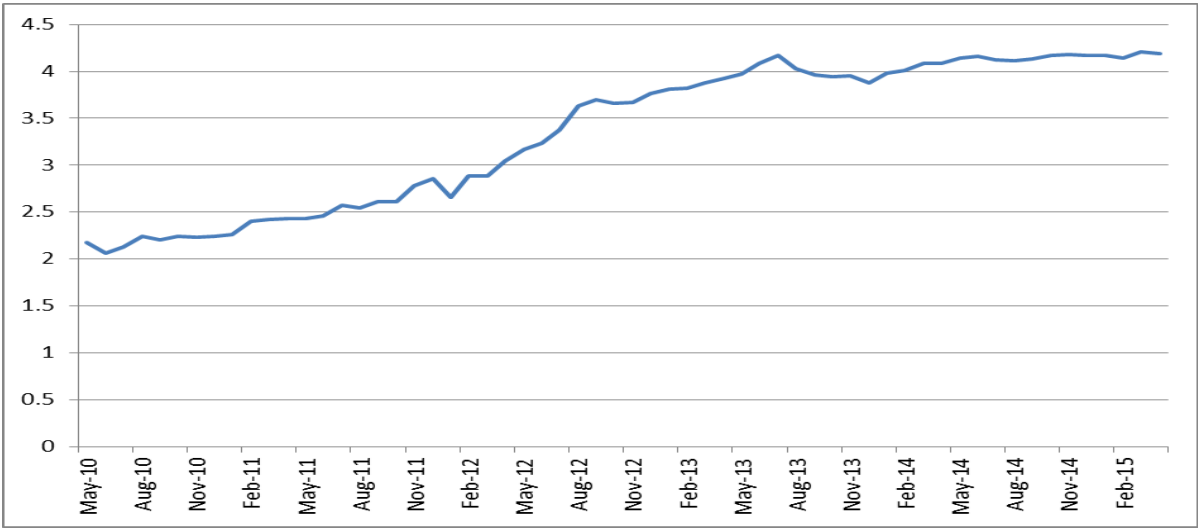


Figure 3: Growth in Average Inverter Capacity (kVA)

The capacity increase has a direct impact on the expected PV penetration on distribution transformers across the network and the number of areas with potential power quality problems that need to be addressed to meet legislative obligations. The revised regulatory proposal has not included an allowance for additional monitoring to address this increase.

Table 3: Comparison of Original and Revised Cumulative Forecast Growth

	Forecast					
	2014-15	2015-16	2016-17	2017-18	2018-19	2019-20
	Number of connections					
Original proposal	294,000	324,000	354,000	384,000	404,000	419,000
Revised proposal	292,909	322,519	347,791	372,317	396,142	419,382
% Difference	-0.4%	-0.5%	-1.8%	-3.0%	-1.9%	0.1%
	Installed Capacity (kVA)					
Original proposal	924,000	1,026,000	1,129,000	1,231,000	1,390,000	1,352,000
Revised proposal	987,000	1,111,362	1,217,504	1,320,514	1,420,579	1,518,187
% Difference	6.8%	8.3%	7.8%	7.3%	9.3%	12.3%

Note: The original forecast was rounded to the nearest '000 connections. The revised forecast displays the raw values derived from Energen's forecast econometric model (as described in Appendix 4.9, Energen Solar PV Connections Forecast).

6 LV Monitoring Business Case

6.1 Other Distributors

In its preliminary decision the AER stated that “*Energex’s proposed level of network monitoring is above the level of power quality monitoring present at most network operators*”. However, Energex is aware that in Victoria, distributors have had long standing requirements to monitor voltage at the extreme of one feeder from every zone substation (ESC Electricity Distribution Code, May 2012, Version 7). These regulatory requirements pre-date any consideration of voltage rise from embedded generation sources, which is the substantial issue that Energex now faces. Accordingly Energex has considered the extremity of its feeders as a reasonable basis for monitoring 11kV voltage regulation (transformer monitoring) and applied a similar principle of worst case monitoring for LV circuit voltage regulation.

4.2.6 A **distributor** must monitor and record:

- steady state **voltages** and **voltage** variations at each zone substation in its **distribution system** which are outside the limitations specified in Table 1; and
- steady state **voltages** and **voltage** variations of a duration of more than one minute which are outside the range of steady state **voltages** specified in Table 1 at the extremity of one feeder **supplied** from each of those zone substations.

Since the monitoring requirement was included in the ESC Code, there has been a very significant increase in monitoring capability through the mandated roll-out of smart meters in Victoria (and NSW) to customer’s premises. This has substantially increased the capability of distributors to monitor voltage delivered to customers with no additional requirement to install LV monitoring on their networks.

Unlike distribution network service providers in New South Wales and Victoria, communication enabled meters are not installed at domestic customer premises to access network data for analysis purposes in Queensland. Most customer metering in areas likely to be impacted by high solar PV penetration are single phase and manually read. These meters are not able to be upgraded to remote reading without retrofitting a separate communications power supply, which would be more expensive than replacing the entire meter. The option to manually read these meters is considered further.

As noted earlier, Energex’s situation in terms of solar PV penetration is not comparable with other states. Aurecon’s independent analysis confirms that Energex is experiencing penetration of Solar PV installations per LV area (per transformer) that exceed those experienced by other utilities by a factor of between 2 and 8 times. When LV design criteria and planning standards are also considered, Aurecon concluded that Energex is likely to require greater levels of monitoring than any other distributor in Australia.

6.2 Drivers

Energex’s regulatory proposal identifies the strategic drivers for an LV monitoring program. Traditionally, distribution networks were designed to accommodate the flow of power in one direction from the substations through to the customer. Basic maximum demand indicators were relied upon to identify limitations on distribution transformers.

The growth in solar PV and the increasing levels of reverse power flows between the LV and 11 kV networks means that more continuous monitoring is required. Currently it has been identified that up to 40 feeders in the 11 kV network are exporting power back into the 11 kV bus at various zone substation during certain periods of the day at certain times of year (cool days in spring or autumn with sunny/clear sky). There are around 350 11kV feeders with more than 1000 kVA of connected solar PV capacity and more than 6,000 distribution transformers with solar PV penetration above 30%. The 30% threshold is the level above which generated power is expected to exceed the daytime load and is a planning limit that some distributors apply for assessment of solar PV connection applications.

Energex has proposed new monitoring programs that extend beyond the transformer terminals to the end of targeted LV circuits to support safety and legislative obligations. The key limitations of the current monitoring which reduces Energex's ability to meet these obligations are:

- Do not know current level of LV voltage compliance
- Existing monitoring does not address LV voltage regulation
- Projected impacts of solar PV on voltage
- Future potential impacts of battery storage
- Detection of neutral problems and dangerous voltages
- Not sufficient to develop and prioritise remedial program

Given Energex has an increasing number of power quality complaints being driven by solar PV, the proposed monitoring programs are a critical element in managing current and future potential safety and legislative risk. The monitoring programs do not factor in the expected growth in solar PV connections over the next five years and are therefore expected to be the minimum required. The prudence of the programs is further discussed in the next section.

6.3 Prudence in Capex Expenditure

6.3.1 Scale & Scope

Energex has developed its monitoring program to meet its Safety and Regulatory Compliance obligations while minimising the CAPEX and OPEX expenditures for remediating the LV network. As shown in Table 4, the scale of the program is relatively small compared to the total population of potential monitoring sites but are well targeted towards the areas that are likely to be impacted. There is a mix of transformer monitoring, which extends capability further into the rural and semi-rural network where voltage regulation is critical on the 11kV network; and LV circuit monitoring to monitor voltage delivered to customers. Both transformer monitoring and LV circuit monitoring are complimentary to managing voltage regulation to customers and is also required to evaluate in-line LV circuit network solutions.

Table 4: % of Population Monitored

Program	Criteria	No of Units	% of Target Population	% of Total Population
CA15 Transformer	3-phase Pole transformers rated 100kVA or less and at the end of the 11kV circuit	300	67% of rural feeders	3% of transformers
	3-phase Pole transformers rated 100kVA or less with solar PV generation penetration >25% of transformer rating and supplying LV circuit(s) >400m	1554	80% of transformers	3% of transformers
CA44 Transformer	3-phase Pad mounted transformers at the end of the 11kV circuit	750	60% of urban feeders	2% of transformers
	3-phase Pad mounted transformers with solar PV generation penetration >25% of transformer rating and supplying LV circuit(s) >400m	1000	90% of transformers	2% of transformers
CA48A LV Circuit	No. supplied by a monitored transformer with solar PV generation penetration > 25% and with circuit > 400 meters in length	1,800 (3ph)	60% of transformers 20% of LV circuits	4% of transformers 1% of LV circuits
CA48B Customer Premise	No. supplied by a monitored transformer with solar PV generation penetration > 25%	2,100 (1ph)	8% of transformers 3% of LV circuits	1% of transformers 0.3% of LV circuits 0.2% of customer premises
	No. supplied by a monitored transformer with circuit > 400 meters in length	2,100 (1ph)	10% of transformers 3% of LV circuits	1% of transformers 0.3% of LV circuits 0.2% of customer premises

The monitoring scoped in Energex’s regulatory proposal covers the five year funded period and is targeted at the areas forecast to have power quality issues that do not meet legislative compliance. Programs were phased over two regulatory periods only where the risk was considered manageable to do so, with the highest priority sites all addressed within the first five years where the programs were new.

Aurecon has separately considered Energex proposed monitoring program from a statistical sample perspective. It found that Energex's sample size is likely to give reasonably significant (95% confidence), dataset of information with approximately +/- 2% accuracy, which may be sufficient to quantify and understand the complexity of the problems being faced. *"It is unlikely that monitoring levels significantly lower than those proposed will be effective. Insufficient levels of monitoring will yield unreliable results, and will effectively be a waste of resources. Correct selection of the monitoring sample is critical if the data gained is to be of any use."*

6.3.2 Options for LV Management

To estimate the impact on the network, Energex has relied on simple models (using common programs like Excel) to model the network impedances and loads and assess the impact of the various network solutions. These simple models have a range of assumptions and can generally only consider and identify worst cases.

The advantage of the simple models is the low to moderate cost and resourcing needed to set up the models. In order to obtain confidence with the simple models, there will need to be load monitoring to validate the model calculations. The simple modelling approach is covered further below and in Appendix B. In the long term Energex would like to develop a complete Low Voltage 3 phase model of the Energex network and identify the most appropriate mitigation actions for the level of unbalance and solar PV penetrations. The PV and Load inputs will need to be stochastic and be able to be applied to LV connectivity models. This is not considered a practical option at this stage, although some work is being conducted in Universities that may assist in the future.

Currently the level of monitoring is not sufficient to develop robust models that can be applied across the entire LV network with varying levels of solar PV penetration and LV circuit lengths. The program proposed will provide the required information to fully calibrate the models and assist with voltage investigations and remedial works in the long-term. In the short-term it is imperative that legislative compliance is achieved.

In order to validate the simple models and develop the long-term models, Energex needs to increase the level of observability of the LV network by monitoring at both the distribution transformer terminals and at the end of LV circuits (as a proxy for what the customer receives). Ad-hoc measurements are generally not suitable for this purpose as observation periods are limited and statistically weak, particularly given the daily and seasonal variation of loads and solar PV and the variations in network topologies.

Energex has considered an alternative to permanent monitoring comprising a targeted manual reading program of customers with electronic metering associated with solar PV connections. These electronic meters store consumption and voltage data for up to three months before it is overwritten. The equivalent cost of this program for the same scope is compared to Energex's proposal in Table 5 and is shown to be of higher cost and was not considered further.

Table 5: LV Monitoring Options Analysis

2014-15 \$ Direct	Capital Cost per site \$	Operating Cost \$ per site p.a.	Amortised Cost ¹ per site \$ p.a.
Option A	Permanent Monitoring		
Distribution Transformer (3ph)	4,853	35	528
LV Circuit (3ph)	3,882	35	430
LV Customer (1ph)	354	35	70
Option B	Survey		
Manual read Customer Meters	na	770 ³	

Note:

1. Amortised cost applies a discount rate 5.8% and 15 year life to the capital cost and adds the operating cost
2. The operating cost includes telecommunication system and staff costs
3. Meter EM1000 single phase consumption and voltage data (3 months of data). Based on reads for CSIRO study of 1000 sites; involved 5 crews full-time for almost 4 weeks. This gives around 7 sites per day per crew. For a more distributed monitoring program across the network the density is lower as we would only target a few meters per distribution transformer. Assume 5 sites per day per crew; crew cost is \$120 per hour for an 8 hour day; 4 reads per year per meter site: cost is $\$120 \times 8 \times 4 / 5 = \770 per site p.a.

6.3.3 Risk Assessment

A risk assessment for the high penetration of solar PV assessed the risk as Medium Risk. A worst case safety risk scenario for high solar penetration is a high voltage (above 260 V) at a premise causing equipment/appliance fire, leading to house catching fire and multiple fatalities. A further risk scenario with the consequence being multiple equipment damage and a house fire was assessed as a Medium Risk.

The reasonable and practical control measures which have been identified to mitigate the risk of high solar penetration were:

1. LV monitoring program (monitors installed at the ends of LV circuits and Neutral integrity at the pole mount transformer).
2. Distribution tap re-setting program

A further risk assessment was conducted with the above short term measures; LV and neutral integrity monitoring implemented, and the risk score reduced to Low to Medium risk. The distribution transformer re-setting program was considered separately because it is a long term solution which will take several years to implement. The risk score for the tap resetting program along with the LV and Neutral integrity monitoring implemented came to Low risk range and is deemed to be ALARP as shown in Figure 4.

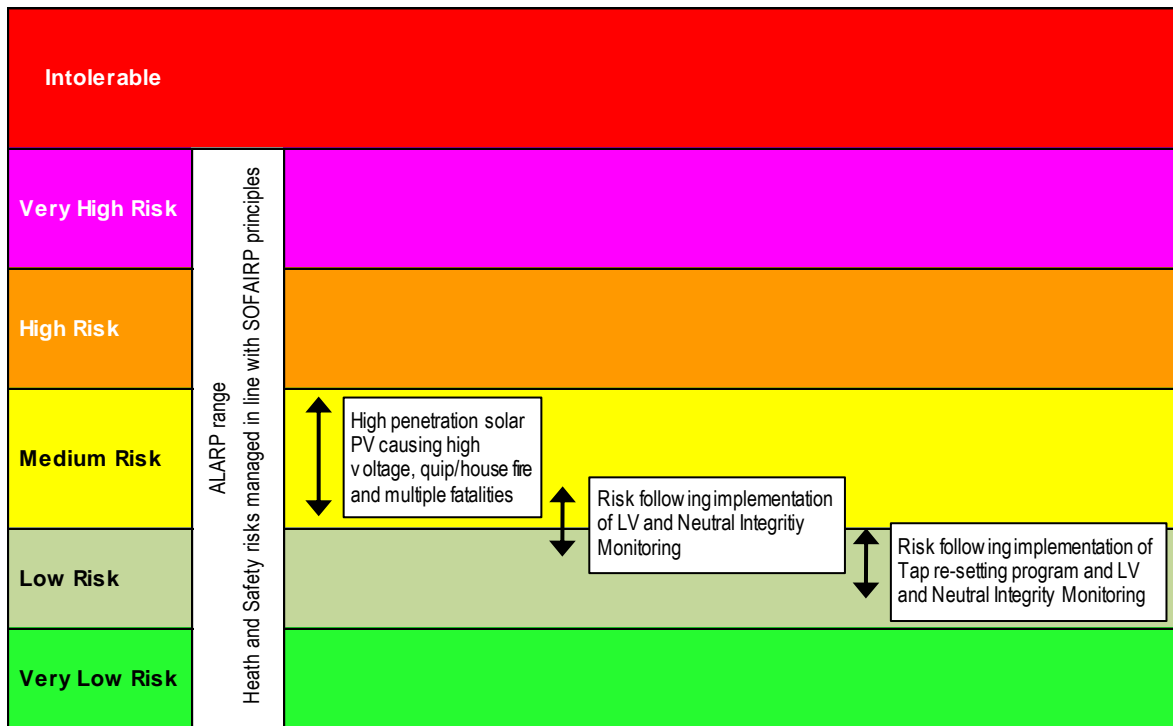


Figure 4: Safety Risk Score for High Penetration Solar PV

The adjustment of the maximum inverter set point voltage was also considered but was judged to be costly and impractical to implement on a wide scale because of the number of solar PV systems, the need for computer equipment and password to access the firmware in the inverters, the hundreds of different inverters installed and the number of solar installers which no longer conduct business and the cost to enforce.

6.4 Financial Benefits Analysis

Although the power quality monitoring programs were justified on the basis of Energex’s safety and compliance obligations, the investments financial benefits were also factored into reductions in reactive work expenditures. Table 6 provides the expected financial OPEX and CAPEX savings with the payback period. Supporting information is provided in Appendix A with the OPEX and CAPEX assumptions summarised in Table 7 and Table 8.

Table 6: PQ Monitoring Financial Cost / Benefit

Category	Program Cost \$m	Program Saving \$m	Payback period years
OPEX		1.8	
CAPEX	25	3.3	
Total	25	5.0	5

Table 7: PQ Monitoring Opex Financial Savings Assumptions

Category	OPEX Business Benefit Assumptions
Maximum Demand Indicators (at transformer)	The cost of reading a single Maximum Demand Indicator (MDI) is around \$150 per unit with the minimum cycle time of once every five year given a low demand growth scenario. No quantitative saving for MDI reads has been included as Energex now has the MDI program included in its cyclic inspection program. Although there would still be some savings, it is difficult to quantify what these would be.
Voltage Investigations	<p>Remote monitoring with standard corporate report saves travel costs to site for two visits to setup and recover ad-hoc monitoring equipment at two locations – distribution transformer and customer premise; reduced specialised PQ ad-hoc monitoring equipment and software including training; reduced staff risk conducting the field investigations.</p> <p>Energex currently does 100 voltage investigations per month. Of these investigations, 40% are related to solar and require a formal voltage investigation with ad-hoc monitoring equipment installed.</p> <p>The installation of permanent LV monitoring capability is expected to reduce the investigation time by around 3 hours (removes the need to install the PQ equipment) at a cost saving of \$720 per investigation. This gives an expected OPEX savings of around \$350,000 p.a (40 investigations x 12 months x \$720 saving). The five year savings are \$1.75 Million.</p>
Insurance Claims	Once every three years there is a significant loss of neutral electrical incident which causes substantial equipment and appliance damage in the range \$300,000 to \$600,000 (this occurred on the South Coast of Energex’s supply area in 2014 where up to 100 homes were impacted by this incident). The insurance losses over the last five years for major neutral current events has averaged around \$260,000 p.a. High voltage damage caused by increasing solar PV is expected to add around \$40,000 p.a., so overall bringing the expected insurance claims to \$300,000 p.a. If the LV circuit monitoring covers 5-10% of the impacted areas, then a benefit of up to \$30,000 p.a. is expected. Combined with transformer monitoring of the neutral, a total benefit of \$60,000 p.a. may be achieved (20%). Although not a significant cost benefit, better monitoring of these events will lead to better safety outcomes for the customer.

Table 8: PQ Monitoring Capex Financial Savings Assumptions

Category	CAPEX Business Benefit Assumptions
Reactive Augmentation	Based on Energex’s historical spend, a flat allowance for customer initiated (reactive) augmentation works of around \$11 Million p.a. was included in Energex’s Augex capital spend for distribution works. If we assume a 6-8% saving can be achieved commensurate with the level of monitoring and the expected increases in voltage complaints over the next five years (currently 10% p.a.) then a saving of around \$660,000 is considered feasible. This will partially offset the expected increase in reactive costs due to voltage complaints. The five year savings are \$3.3m

6.5 Conclusions

Energex has demonstrated that there is a robust strategy supporting the targeted installation of LV monitoring that addresses Energex safety risks and legislative obligations to manage voltage within prescribed limits of 240V \pm 6% at customer terminals.

The monitoring program will address safety risks in targeted areas by being able to monitor potential deterioration in asset performance such as loss of neutral and be able to respond proactively to avoid high safety consequences such as equipment damage and house fires.

There are also financial savings in voltage investigations costs by reducing the labour component to install and recover temporarily installed monitoring equipment of \$350,000 p.a. Within the next 5 years there are capital savings expected in reactive augmentation costs of \$660,000 p.a. These savings have already been factored into Energex's original CAPEX and OPEX forecasts in its Regulatory Proposal.

Longer-term better analytics will assist Energex to lower overall capital costs of managing voltage across the network, support the introduction of the proposed 230V standard, proactively improve power quality to customers to achieve legislative compliance and reduce organisational risk.

7 Remediation Business Case

7.1 Prudence in Capex Expenditure

7.1.1 Scale and Scope

In its regulatory proposal, Energex's capital expenditure program for dedicated power quality remediation works totalled \$13.4 million over the five years and addressed 840 network areas. This equates to an average cost of around \$16,000 per site.

Figure 5 shows the number of forecast solar PV distribution transformer areas exceeding various levels of penetration over the five year period. Out of a total population of 48,000 transformers there are around 8,000 transformers expected to exceed 25% penetration by 2015/16 and in excess of 12,000 by 2019/20.

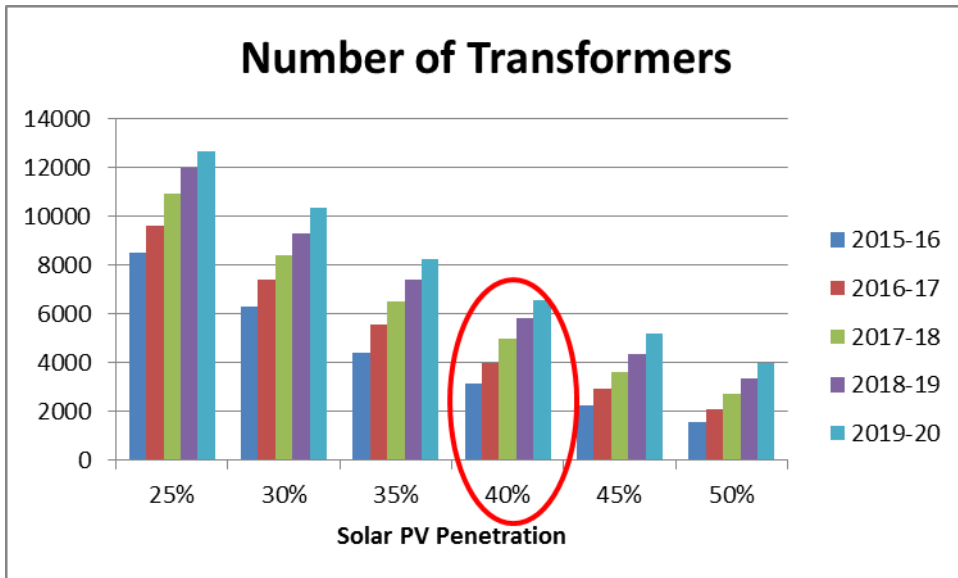


Figure 5: Forecast Number of transformer areas exceeding solar PV thresholds

Based on Energex’s models and measurements, the number of areas forecast to have issues requiring an augmentation solution was determined for solar PV penetration levels exceeding 40% of the local transformer rating and LV circuit lengths exceeding 600m. Voltage issues generally occur where Energex LV circuit lengths exceed 400 m (LV circuit lengths to the customer can add a further 400 m).

The number of impacted areas identified by these criteria as a proportion of the total transformer population is small representing less than 2% (but is up to 17% of transformers which have solar PV penetration above 30%). The number of impacted areas is also a small compared to the number of distribution transformers previously identified with high voltage of around 10% of the monitoring transformer population.

Although the selection criteria used by Energex are based on simplified models, evidence suggests that the assumptions made are reasonable and prudent.

As outlined earlier, Energex has reviewed its Solar PV connections forecast and revised upwards the expected increase in installed inverter capacity based on historical trends and market indicators. The impact of this change on the proposed remediation program for each of the years is shown in Table 9 with sensitivity analysis of $\pm 20\%$ applied to the forecast. Figure 6 also shows the original and proposed forecasts with the sensitivity bands overlayed in blue and red respectively compared with the original remediation program. Given forecasting tolerances, Energex will manage this increased risk with no increase to the original proposed expenditure.

Table 9: Forecast Areas Impacted

Solar PV Connections Capacity Forecast	Sensitivity	Number of Sites Impacted (Issues) Forecast				
		2015-16	2016-17	2017-18	2018-19	2019-20
Original	20%	439	616	802	920	973
	0%	431	584	727	830	901
	-20%	421	539	653	742	800
Revised	20%	481	654	829	959	1095
	0%	449	597	739	867	967
	-20%	420	530	643	762	856

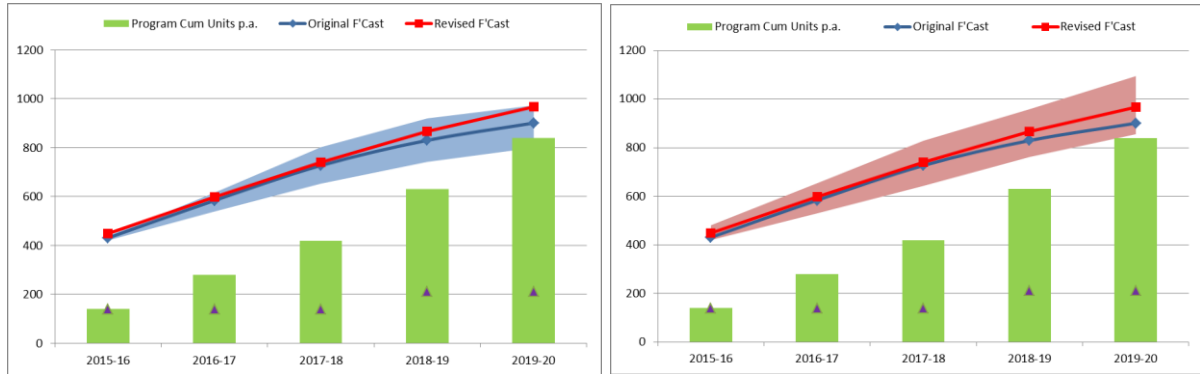


Figure 6: Existing and Revised Forecast Areas Requiring Remediation Compared to Program: Sensitivity $\pm 20\%$ of Forecast

With reference to the average program cost of \$16k per site, this allows for a new F transformer to be installed and the LV circuit to be reconfigured to reduce the average LV circuit lengths. This is on the low side of detailed estimates for 18 projects of similar scope to address voltage complaints which averaged around \$65,000 per site. The projects ranged in cost from \$24,000 to \$170,000 with the large variations mainly due to differences in transformer capacity and length of 11kV extension required. Energex supports the proposed unit cost of \$16k on the basis that site selection will be carefully controlled to minimise the requirement to extend 11kV mains.

Aurecon independently reviewed the scope and estimated cost of Energex’s program and considered it to be at the lower end of their estimated range of expected outcomes. This could result in Energex having to manage a higher network risk associated with the impact of solar PV penetration.

While the driver is to resolve a network issue, the solution provides additional benefits for customers in terms of improved voltage regulation to their equipment and appliances and reduced safety risks. The selection of this option is further discussed in the next section.

7.1.2 Options (Network)

Energex has considered the practical range of network options to address the impacts arising from remediating the increasing levels of solar PV penetration, as shown in Table 10. In general, as the solar PV penetration level rises, so does the cost of remedial work.

Table 10 – Network Solutions for Varying Levels of Solar PV Penetration

Solar PV Penetration Level	Network Solutions
From 30% to 70%	<ol style="list-style-type: none"> 1. Balance of PV load 2. Change transformer tap
From 40% to 100%	<ol style="list-style-type: none"> 3. 1 and 2 above 4. Upgrade transformer 5. New transformer 6. Re-conductor mains
From 100% to 200%	<ol style="list-style-type: none"> 7. 1 to 6 above 8. New technology (On load tap transformer, LV regulator, Regformer, Statcom)

As part of its OPEX program, Energex will carry out targeted transformer tap adjustment programs and rebalancing programs to address voltage issues in areas with solar PV penetration exceeding 30%. This is supported by data showing significant numbers of distribution transformer tap settings on non-optimal settings and unbalance of voltages at distribution transformer LV terminals.

With regards to the Network solutions, the following comments are made:

- Balancing the solar PV generation is an effective option when there are large single phase solar PV systems on the smaller distribution transformers (less than 20 customers). Balancing is less effective on the larger distribution transformers (where there are up to 100 customers) and the loads are better balanced.
- A change in transformer tap will reduce the voltage by 6 Volts (2.5%) – this is the main option for addressing high voltage but may not be possible if the customer voltages fall below the regulated limit of 225.4 V at peak load times. Generally only one tap-change increment can be accommodated without compromising the voltage to other customers.
- An upgraded transformer will allow the opportunity to re-set the taps (by 6 volts) and allow higher penetrations of solar PV. This option may not be possible if the pole is not suitable for the additional mechanical loading.
- A new transformer is generally required where the high voltage is caused by long lengths of LV, typically in excess of 600 metres – this may be all Energex LV conductors or part Energex and part consumer mains. The cost for a new transformer installation can be considerable if the 11 kV network has to be extended a long distance.
- Where there is smaller aged conductors (e.g 7/.080 copper) re-conductoring is an option to reduce voltage rise/drop and maintain LV within regulated limits. Modelling indicates that re-conductoring 7/.080 with LVABC can halve the voltage rise.
- Some of the newer technologies (e.g on load tap changer) are expected to cost more than an upgraded transformer, but less than the installation of a new transformer, but others (e.g STATCOM) is expected to be at a similar cost to a new transformer. The STATCOM does have other advantages as it can offset peak load with the use of the battery storage.

Energex presented results showing the impact of solar PV on voltage rise in its Regulatory Proposal. Further modelling is presented in Appendix B that supports the earlier findings. These results are

summarised in Tables 11 and 12 for the urban and semi-rural networks and represent typical network topologies for varying levels of penetration.

These results show the dramatic voltage rise impact of (1) increasing levels of solar PV penetration on networks and (2) connection of large single phase inverter loads (up to 10 kVA) typical on semi-rural networks. Further, these results are expected to understate the full potential impact, as they do not consider the combined interaction of the 11kV and LV network, as confirmed by Aurecon’s independent modelling.

Given that Energex sets its transformer taps in the range of 242 V to 250 V in order to allow for voltage drop caused by peak load, the scope for voltage rise is in the range of 2% (5V) to 5% (12 V) before regulated high voltage limits are reached. In the older networks, where bare copper conductors are used, the voltage rise will be even higher (typically up to 2%).

Table 11 Voltage Rise Calculations on Urban Network with Increasing Levels of PV Penetration

Urban Study 1	Max Voltage Rise (Balanced Load)	Max Voltage Rise (Light Unbalanced Load)
29% PV Penetration	1.2%	2.0%
57% PV Penetration	3.3%	5.3%
95% PV Penetration	6.0%	9.7%

Note: A tap-change can generally only achieve a 2.5% improvement so will not be a viable option for PV penetration above 40%-50% range. With longer LV circuit lengths >600m, only an augmentation solution is expected to be effective in reducing voltage rise.

Table 12 Voltage Rise Calculations on Semi-rural Network

Semi- Rural Studies	Max Voltage Rise (Balanced Load)	Max Voltage Rise (Unbalanced Load)
1 x 10 kVA Inverter		10.2%
3 x 10 kVA Inverters	4.4%	

7.1.3 Options (Customer)

Energex has considered non-network options to address the safety risks and regulatory obligations. As previously outlined in Energex’s response to AER questions, the enforcement of overvoltage protection trip settings is not considered a practical response to managing voltage issues and was not considered to mitigate Augex expenditure (refer Response EGX10). Enforcement of these settings without some work by Energex to adapt the network and set transformer tap on their optimal settings would result in widespread complaints and result in more reactive and less optimal responses to mitigate the issues.

At present there is no practical way of adjusting these settings without the full cooperation of solar manufacturers and installers, as there are a large number of inverter manufacturers, and a number of solar installers who have gone out of business. It would require a computer to be connected to the customer’s inverter to change any of the firmware settings. These are password protected and this will have to be obtained from the manufacturer or solar installer.

In the longer term, Energex's revised connection's policy (refer section 7.2 and Appendix C) is expected to support minimum compliance standards for customers and help to mitigate the future impacts on voltage. Based on the current penetration of solar PV and the issues currently identified, these options will not offset the current Augex requirements.

7.2 Risk Assessment

Energex considers the risk of elevated voltages causing multiple equipment damage / fires to be low to moderate. However Energex has a legislative requirement under the Queensland Electricity Regulations to maintain voltage within 240V nominal $\pm 6\%$. The remedial program is required to ensure Energex meets its obligations and will assist in reducing safety risks of high voltage causing equipment failure.

7.3 Conclusions

Energex has reviewed the basis for its proposed remediation program to meet safety and regulatory obligations. The revised solar PV connections forecast even without the contribution of the Qld Government aspirational 2020 target, is shown to be sound and supported by market indicators, and is substantially below that forecast by AEMO. Rather than being on the high side, Energex's original forecast was demonstrated to be on the low side after taking into account more up to date figures on the average size of inverters which have increased from 3 kVA to 4 kVA. The number of non-compliant areas is shown to be directly impacted by the revised connection forecast. Considering sensitivity analysis around the number of connections, Energex has opted not to change its originally proposed expenditure. Energex has demonstrated that the Augex is prudent in terms of scale and scope and considerate of other network and customer options based on the supporting evidence presented.

Aurecon considered that Energex's program is at the lower end of our estimated range of expected outcomes and concluded that Energex may have to manage a higher network risk associated with the impact of solar PV penetration.

8 Other Factors

8.1 230V Standard

The power quality programs proposed are based on the current regulatory requirement to maintain statutory voltages within the range 240 V $\pm 6\%$ and will mainly address worst areas emerging from the growth of Solar PV on the network. The introduction of the 230V Australian Standard has not been factored into any specific program cost savings, as its introduction was assumed to be towards the end of the next regulatory period. Given the current and forecast levels of Solar PV penetration on the network driving voltage issues, the worst impacted areas would still need to be addressed, even if a 230V standard was in place early. However its introduction should give greater flexibility to manage voltage and help to mitigate the growth in voltage related issues once distribution transformers have been adjusted to their optimal tap settings into the 2020-25 period. The cost of this transition program over a realistic timeframe will be considered in Energex's future funding proposals.

The cost of implementing the 230V standard is not included in Energex’s original and revised proposal. Energex’s 230 V discussion paper identified a significant number of distribution transformer taps that will need to be changed to accommodate the new upper and lower limits and address the non-optimal current settings. Figure 7 shows an example extracted from Australian Standard AS 61000.3.100 of a typical site with its voltage distribution superimposed against the 230V standard lower, upper and preferred voltage ranges. For product harmonisation purposes, the standard nominates a preferred operating zone of 230V +6% to -2% (225.4V to 243.8V) which may be considered a long term goal.

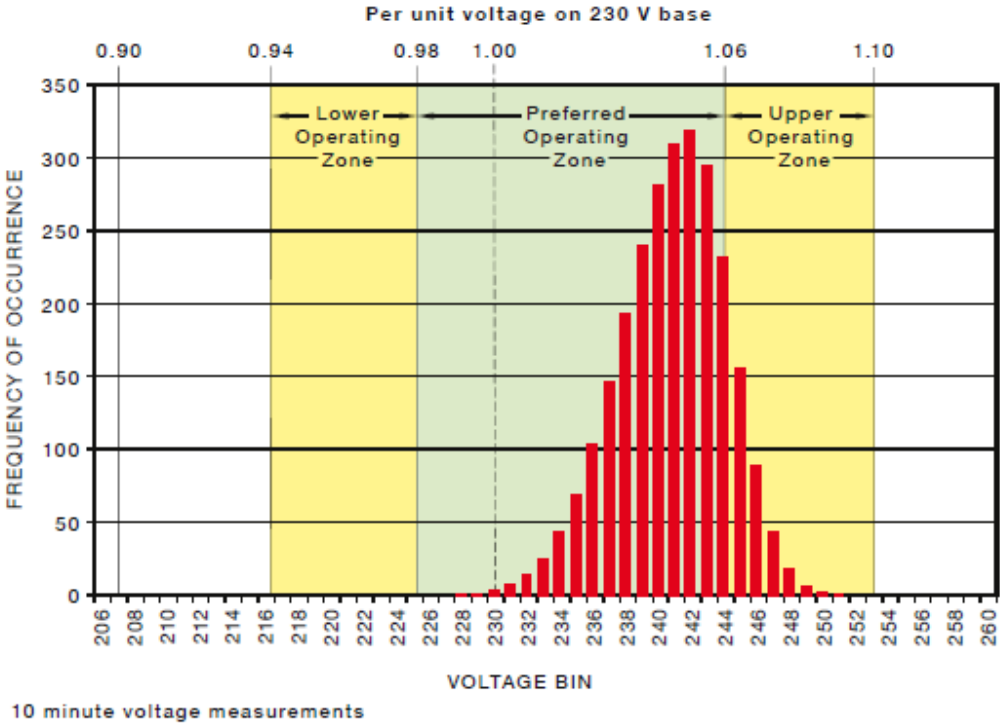


Figure 7: 230 V Illustrated Example showing per unit limits (Source Australian Standard AS61000.3.100)

8.2 Connections Policy

Energex has pro-actively engaged with customers and the solar PV industry and has developed streamlined processes and information to guide customers and solar PV installers. Energex’s internet website provides information to customers on application process, responsibilities of solar PV owners, FAQ of the solar bonus scheme. For solar installers, Energex website provides information on the installation process, FAQ on reading the meter and access to solar related data. Further, Energex representatives have attended and presented at key industry forums and workshops, provided regular briefings to key stakeholders including the State Government and provided regular information alerts to the solar installers in our region.

Energex has a revised solar PV connections policy which is in the final stages of consultation for an intended release date of September 2015. This policy demonstrates Energex’s commitment to ensuring customer’s connections also meet minimum standards and is adapted to meet the advances offered by new technology and account for the revisions to Australian Standard for grid connected inverters AS4777.2. Appendix C provides a summary of the options available for streamlined

connection. Energex considers the connection policy will provide more equitable outcomes for solar PV customers wishing to connect to the network.

9 Revised Proposal

After reviewing the issues raised by the AER and considering the drivers, regulatory obligations, risks, financial benefits and other factors forming the basis for Energex's original power quality capital forecast, Energex believes these are adequately addressed in the revised proposal. On this basis, Energex does not propose any change to its original proposal for both LV monitoring and remediation works. The program is considered prudent and reasonable considering the challenges presented.

Aurecon's independent review of Energex's revised proposal has concluded that the proposed expenditure for monitoring and remediation is the minimum expenditure to achieve the required outcomes.

\$m, 2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	Total
Energex original proposal	5.8	4.9	4.9	11.4	11.5	38.4
AER preliminary decision	3.6	3.1	3.1	7.1	7.2	24.0
Energex revised proposal	5.8	4.9	4.9	11.4	11.5	38.4

In summary, the proposed Augex spend is justified based on:

1. The current level of solar PV penetration on Energex's network already identified as causing power quality issues with increasing number of customer complaints.
2. The forecast increase in the connected inverter capacity on the network over the next five years will rapidly increase the number of distribution transformer areas expected to have power quality problems.
3. Energex forecast of new solar PV capacity is substantially below that forecast by AEMO, reinforcing that Energex's view of continuing growth in connections is reasonable and supported by market fundamentals.
4. Potential increase in forecast solar PV connections due to Qld Governments stated aspirational targets for 1 million solar PV rooftops in Qld by 2020 is not factored in and presents a further network risk that will need to be managed by Energex.
5. Energex does not have any substantial penetration of remotely read electronic capable meters at customer premises to monitor power quality as in southern states.
6. The take-up of solar PV is substantially greater in South East Queensland than in southern states and as a result the requirement to monitor power quality is commensurately greater.
7. The level of Augex spend on monitoring and remediation works is well targeted to areas expected to be impacted on the basis of measurements and modelling and will produce financial savings that would otherwise result in further increases in reactive expenditures.

APPENDIX A: LV Monitoring Savings

A1 OPEX savings

A1.1 Voltage Investigations

Currently, the primary driver for Energex to investigate the state of an LV network is customer complaints. The process for a voltage investigation is as follows:

- Install temporary (ad-hoc) monitoring using “data loggers”. Data loggers are installed at the transformer terminals and customer premise for a minimum of one week. Depending on availability of equipment, a logger may also be installed at the end of the LV circuit.
- Evaluation of the logger data. Data from the customer’s premise is checked for voltages outside or close to limits to verify that a problem exists. Using the voltage and load profiles at the distribution transformer (and the end of the LV circuit if installed) the crews also check the suitability of the transformer tap and phase balancing.
- Corrective action if required. The preferred solution to a voltage issue is load and solar IES balancing with a change to the distribution tap also considered. In more extreme cases, load shifts or a system augmentation project will be raised after consultation with Asset Management.

Figure A1 shows the customer voltage complaints from the past 4 years, with a total of 1330 received 2013/14. From Figure A1 it is evident that the number of customer voltage complaints is on the rise.

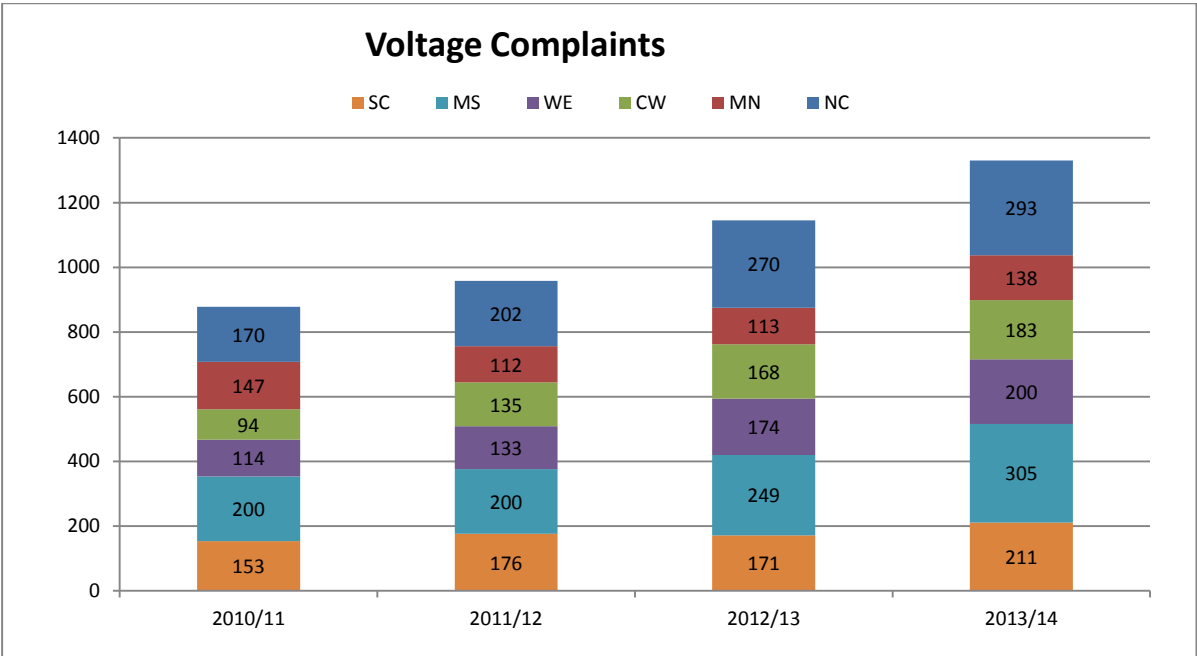


Figure A1: Number of Voltage Complaints 2010/11 to 2013/14

From the available data from two asset areas, the average voltage investigation requires 14 hours. Assuming this figure is representative of voltage investigations across the business, it is reasonable to expect over 18,500 hours equivalent to an expenditure of \$1.3 million annually attending to voltage investigations.

The LV monitoring solution will be able to monitor the voltage and unbalance at positions along the LV circuits continuously and will provide the following benefits:

- 1. Negate the need and cost for the temporary monitors used in the voltage investigation process
- 2. Optimise the transformer taps by identifying the voltage variation at the ends of the feeder over a longer time period and
- 3. Prioritise and minimise the cost with the LV & Solar PV balancing and remedial program

A2.2 High Voltage Incidents leading to Equipment Damage and Insurance Claims

A significant benefit of the LV monitoring solution is that it will assist to avoid equipment damage, house fires and high cost insurance claims. In general, the incident which results in the highest cost consequence to Energex on the LV network is the loss of neutral connection at the transformer (insurance compensation claims in the hundreds of thousands). This is followed by high volts on the LV network – in general widespread voltages above 262 V will result in numerous equipment damage (with compensation claims in the thousands) and then loss of neutral on the LV circuits (compensation claims may be in the thousands).

The neutral integrity monitoring proposed in the CAPEX program is targeted for distribution transformers in the urban area which have the most dense population of homes and will provide the highest benefits.

The LV monitoring program is proposed for areas with high solar PV penetration where there are long LV circuits and where some of the highest insurance claims have occurred (which have included fires)

In regards to the exposure of fire risk to Energex, in 2013 there were 419 property related fires recorded in the Service Call Management system. There were 272 house fires, 73 commercial fires and 74 switchboard fires – as shown in Figure A2.

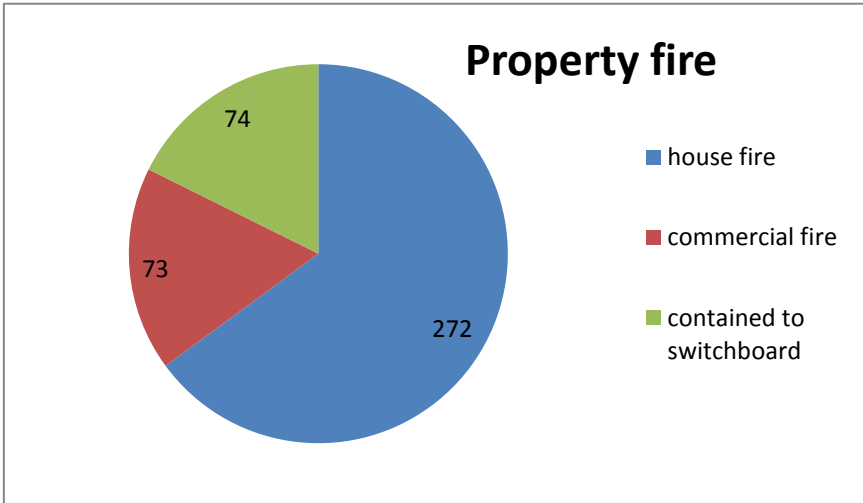


Figure A2: Property Fires recorded in 2013

The LV monitoring program will be able to provide early warning for each of the network incidences which lead to equipment damage and major insurance compensation payments, namely:

1. Loss of neutral at the transformer
2. High voltage at the customer premises
3. Loss of neutral on the LV circuits

The loss of a neutral at the transformer results in the neutral current travelling back to the transformer in the higher resistance path of the general mass of the earth rather than in the much lower metallic neutral conductor. If we assume minimal neutral current is 10 Amp and the ground resistance is 5 ohms, this will cause a voltage shift on the neutral at the transformer of 50 V and this leads to the phase voltages moving from a nominal 240 V to either less than 190 V (- 50 V) or above 290 V (+ 50 V). These large voltage excursions can cause multiple equipment/appliance damage and house fires. This dangerous electrical event is reported to the Electrical Safety Office.

The loss of transformer neutral on a semi-rural transformer in the locality Munruben in early 2000 caused multiple equipment damage, house fires (with one completely destroyed), and hundreds of thousands of dollars in compensation for equipment damage. In 2014, the loss of a neutral at or near a distribution transformer on the Gold Coast caused around \$580,000 of damage to electrical equipment/appliances and impacted residents in 100 homes and apartments.

The loss of neutral at a transformer has generally occurred on an annual basis but the incidents which have caused damages in the hundreds of thousand occurs on the Energex network on an approximate 3 year basis in the range \$300,000 to \$600,000. The insurance losses over the last five years for major neutral current events has averaged around \$260,000 p.a.. High voltage damage caused by increasing solar PV is expected to add around \$40,000 p.a., so overall bringing the expected insurance claims to \$300,000 p.a.. If the LV circuit monitoring covers 5-10% of the impacted areas, then a benefit of up to \$30,000 p.a. is expected. Combined with transformer monitoring of the neutral, a total benefit of \$60,000 p.a. may be achieved (20% of total). Although not a significant cost benefit, better monitoring of these events will lead to better safety outcomes for the customer.

Before solar PV systems were installed in large numbers on the Energex network, the neutral current was generally less than 10 Amps. The higher solar PV penetration has resulted in neutral currents being up to 100 Amps in some locations (refer Figure A3). The high neutral currents are caused by load unbalance, single phase inverter unbalance and third harmonic currents from inverters (solar PV and air-conditioning).

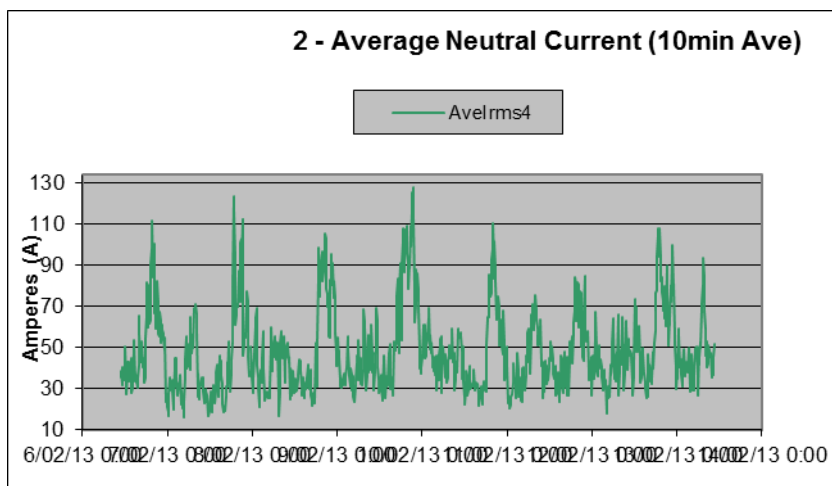


Figure A3: Neutral current on transformer in semi-rural area with > 50% solar PV penetration.

These high neutral currents will cause larger voltage shifts of the neutral with the loss of neutral connections. For the incident on the Gold coast in 2014, the voltage on the phase conductors was estimated to be around 340 Volt (100 Volt above nominal), Given the increasing neutral currents, it is reasonable to expect that the loss of neutral at a transformer which results in a major equipment damages will occur on a more frequent basis, and likely to be annually. There is also an increased likelihood that one will lead to a house fire with the consequence of multiple fatalities. A risk assessment for this risk consequence is given (refer section 6.3.3).

Energex has undertaken measures to address this issue, such as requiring the neutral to be double clamped at the transformer and more recently added double clamping of neutrals in the coastal areas (within 3 km of the coast), The neutral integrity program will also minimise this risk by monitoring the neutral currents. The LV monitoring project will support the initiatives to address this significant risk to Energex.

Although the overall number of resolved and paid insurance claims, referenced in Energex's power quality Strategic Plan, reduced from 2009 to 2013, Figure A4 shows the voltage related insurance claims which were paid out by Energex from 2010/11 to 2013/14 increased. There was one large single claim in 2013/14, but it is reasonable to expect that voltage related insurance claims will cost Energex around \$40,000 per annum. This is expected to increase with increasing penetration of solar PV installations.

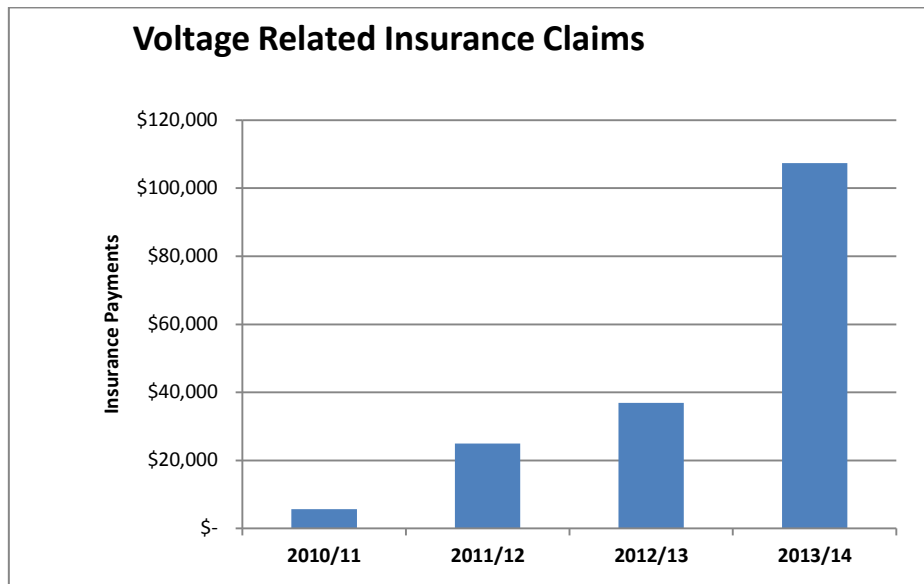


Figure A4: Voltage Related Insurance Claims.

A2 CAPEX savings

Remedial Works

A pilot project was undertaken to determine the cost of capital remediation works in one of Energex asset areas. The solar PV penetration is typical of what is expected across the entire Energex network. Over an 18 month planning period from January 2014 to June 2015 there are 18 approved projects which range in cost \$24,000 to \$170,000 with the average of \$65,000. The projects costs are shown in Figure A5, with the large variations mainly due to differences in transformer capacity and length of 11kV extension required.

This work is reactive in response to customer complaints – the average solar PV penetration is around 46%. All these projects require a new transformer to be installed to split the LV area. If more detailed analysis had been undertaken with long term monitoring data then it is expected that lower cost proactive solutions could have been implemented, including transformer upgrades with new technology (eg regulating transformer, LV regulators, Statcoms). The budgeted expenditure on the remedial program is \$11 Million p.a. under the customer initiated distribution Augex allowance. The LV monitoring program will be installed on around 30% of the transformers with PV penetration >30% and around 8% of the number of LV circuits off these transformers. If we assume a 6-8% saving can be achieved commensurate with the level of monitoring and the expected increases in voltage complaints over the next five years (currently 10% p.a.) then a saving of around \$660,000 is considered feasible. This will partially offset the expected increase in reactive costs due to voltage complaints. The five year savings are \$3.3 Million.

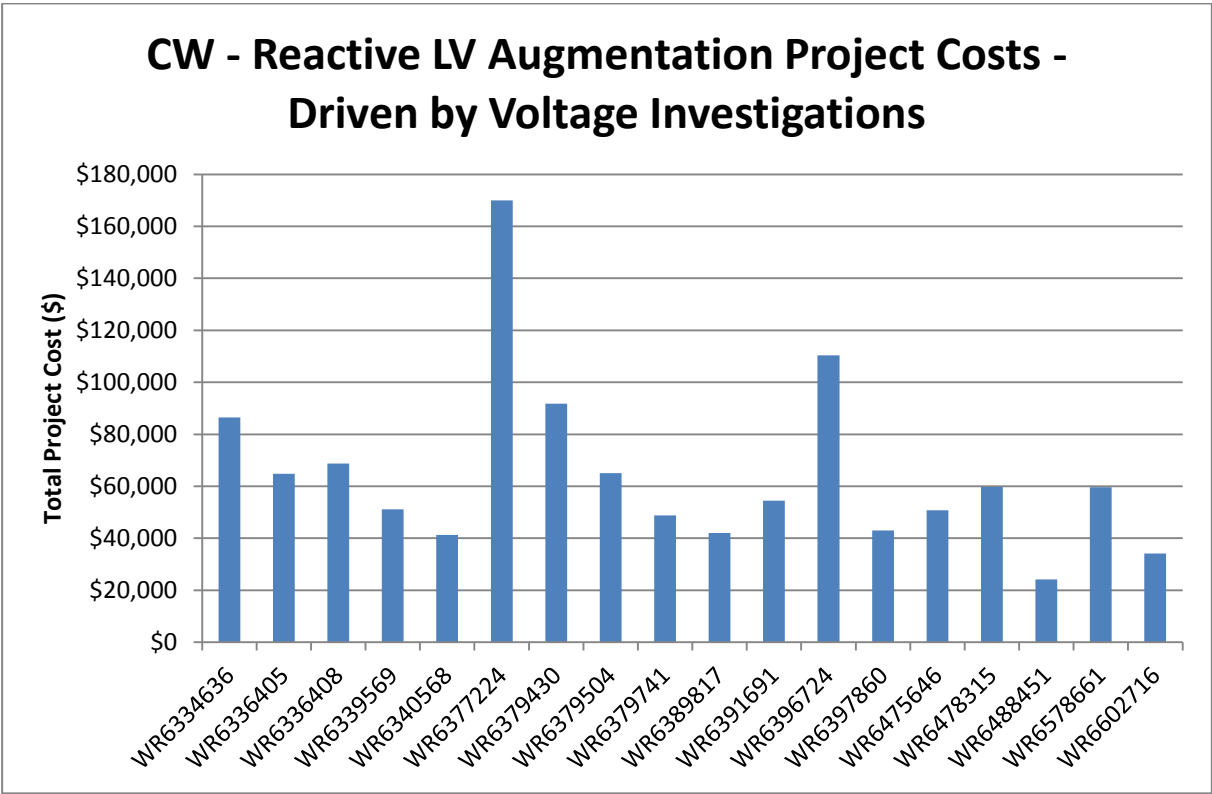


Figure A5: Pilot Project Reactive Capital Augmentation Costs (2014/15)

APPENDIX B: Voltage Rise on LV Networks

A number of LV modelling studies have been conducted to show the impact of high penetration solar PV and large PV systems causing unbalance on the network.

Study 1: Urban Network

Modelling the LV network with a typical 315 kVA transformer supplying 60 customers and an After Diversity Low Demand (ADLD) of 0.5kVA is shown below. Plotted is the voltage rise on an LVABC run of 400 metres supplying 24 of the 60 customers. Figure B1 shows a balanced customer distribution with a **PV penetration of 29%** (1.5kVA per customer) which indicates a voltage rise of over 1% (3 volts).

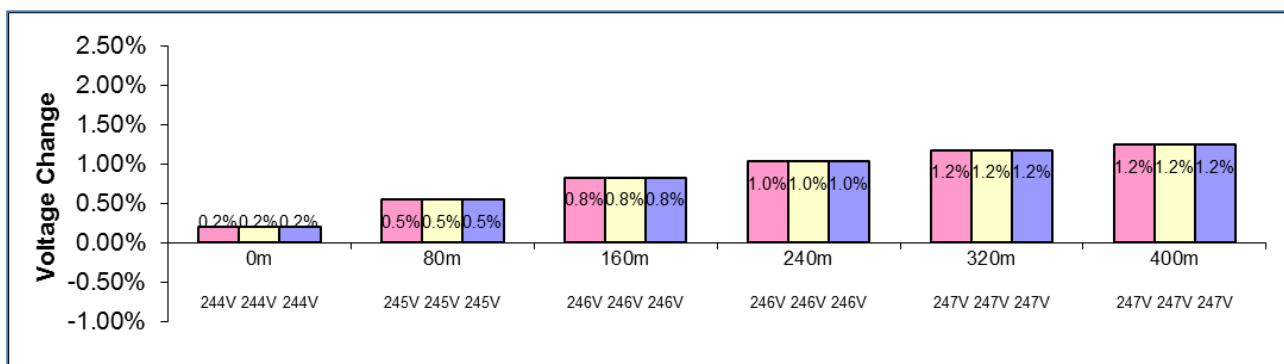


Figure B1 – Voltage rise on LV network with a balanced 29% PV penetration

If the same amount of PV generation is connected unevenly (with more on A phase and less on B phase) the voltage rise increases to 2% (5 volts) as shown in Figure B2.

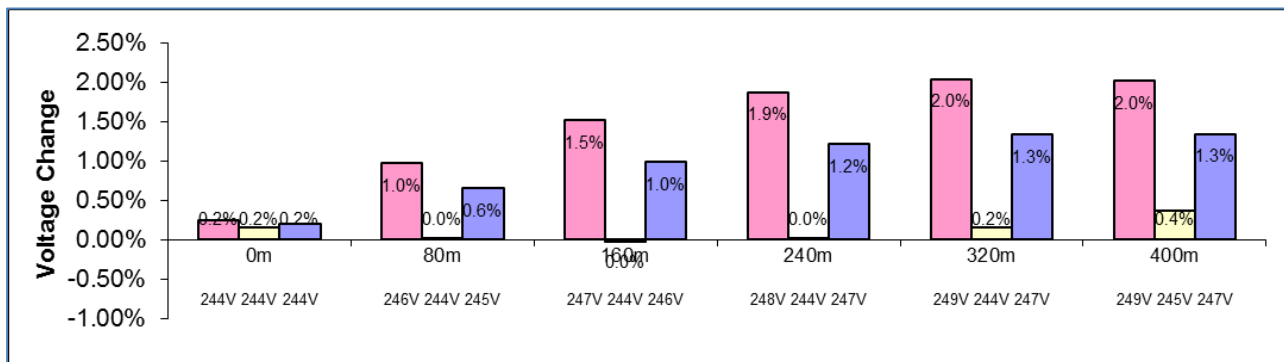


Figure B2 – Voltage rise on LV network with an unbalanced 29% PV penetration

If all the PV inverters are set to sink VARs with a power factor 0.9 on the unbalanced LV circuit the voltage rise can be reduced to below 1% (2 volts) as shown in Figure B3

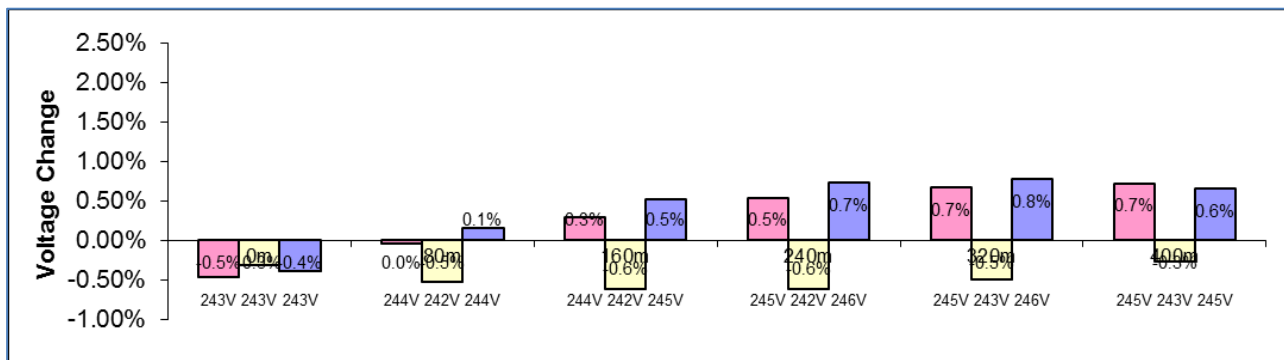


Figure B3 – Voltage rise on LV network with an unbalanced 29% PV penetration & PF=0.9

Increasing **PV penetration to 57%** (3 kVA per customer) results in a 3% voltage rise (8 volts) on a balanced network (see Figure B4), more than 5% rise (13 volts) on an unbalanced network (see Figure B5), which can be mitigated, with inverters once again set to sink VARs at a power factor of 0.9, down to a 3% rise (7 volts) as per Figure B6.

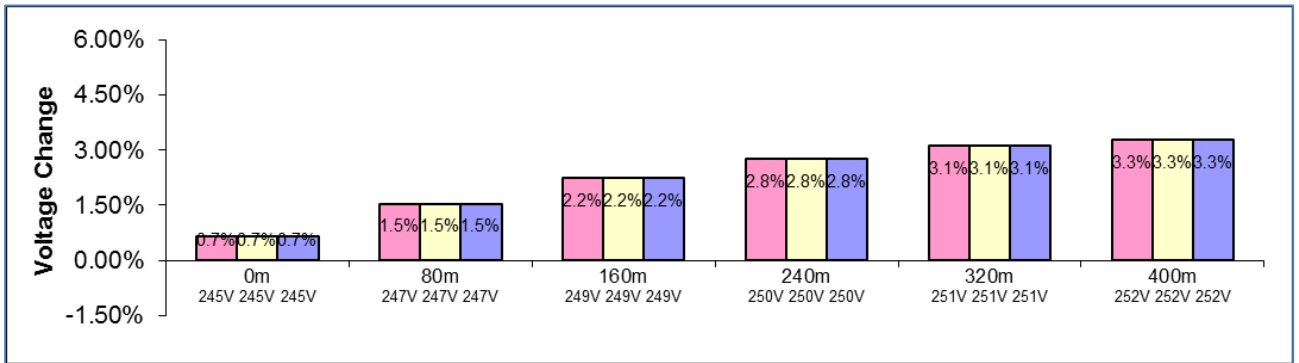


Figure B4 – Voltage rise on LV network with a balanced 57% PV penetration

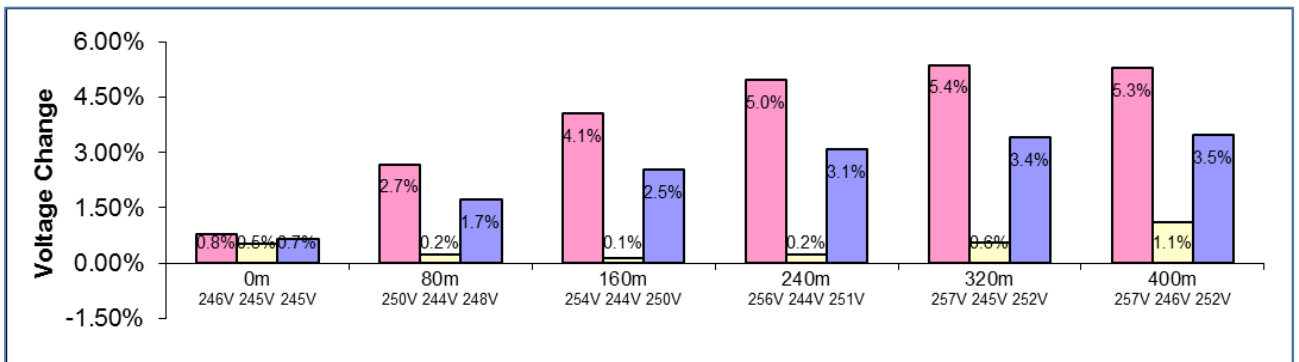


Figure B5 – Voltage rise on LV network with an unbalanced 57% PV penetration

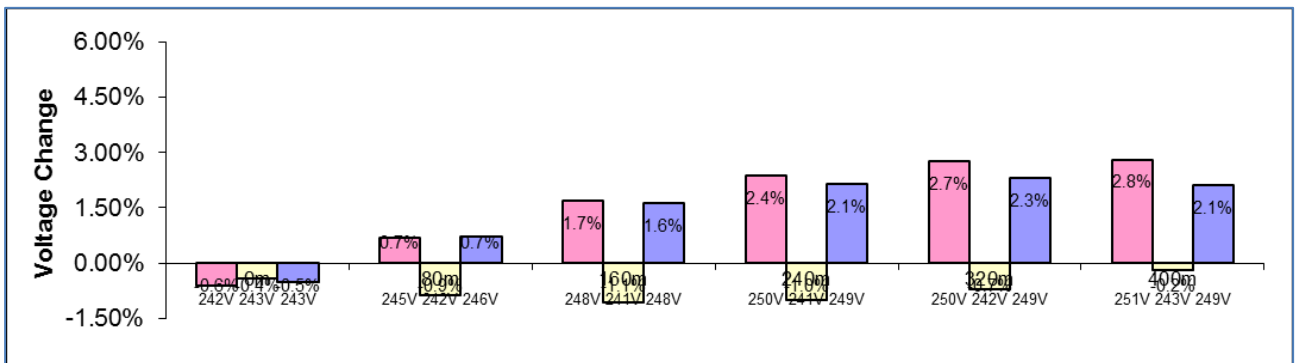


Figure B6 – Voltage rise on LV network with an unbalanced 95% PV penetration & PF=0.9

With all customers connecting 3kVA PV IES current overhead LV design standards may result in customer voltages exceeding upper limits during peak export unless the network is well balanced or all customers are using inverters with reactive control.

Further increasing **PV penetration up to 95%** (5 kVA per customer) results in a 6% voltage rise (14 volts) on a balanced network (see Figure B7), almost 10% rise (23 volts) on an unbalanced network (see Figure B8), which can be mitigated, with inverters once again set to sink VARs at a power factor of 0.9, down to a 6% rise (15 volts) as per Figure B9.

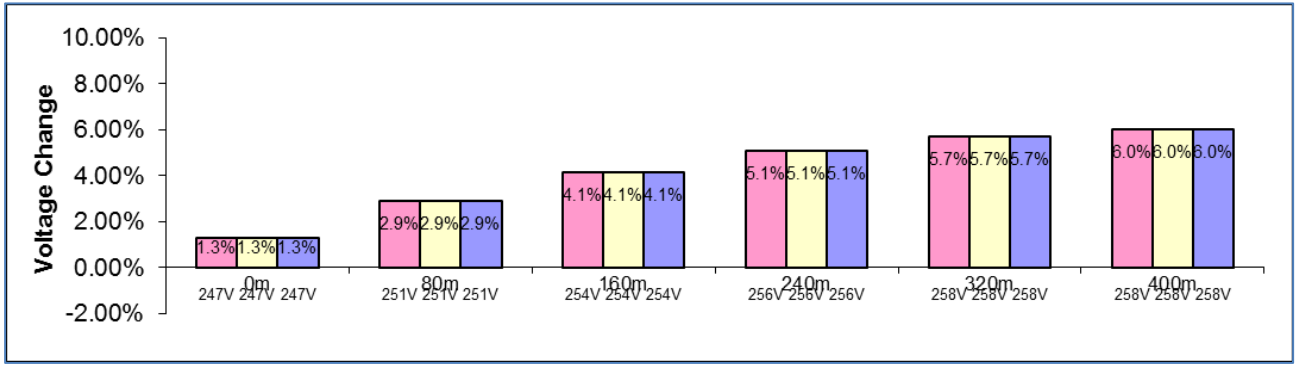


Figure B7 – Voltage rise on LV network with a balanced 95% PV penetration

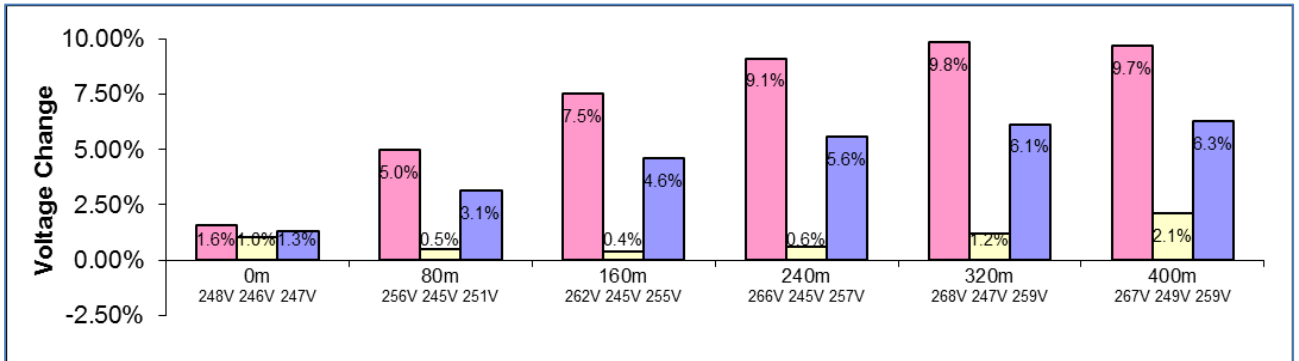


Figure B8 – Voltage rise on LV network with an unbalanced 95% PV penetration

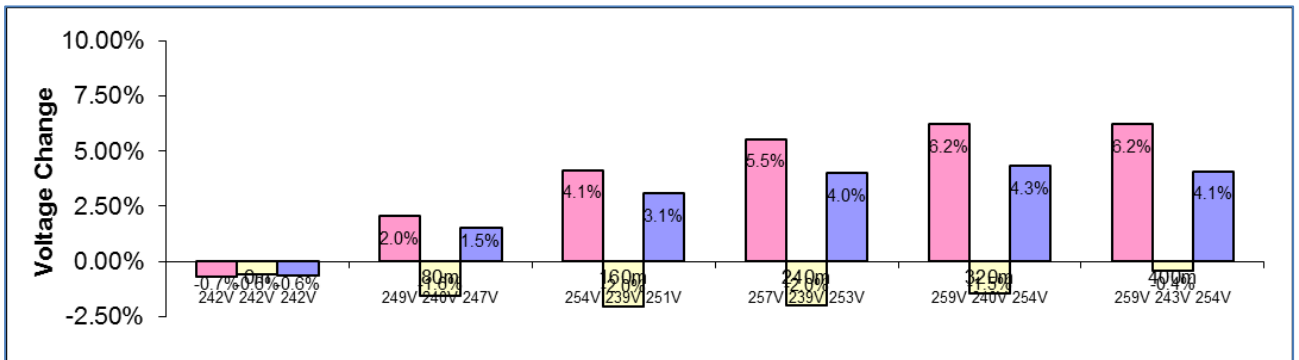


Figure B9 – Voltage rise on LV network with an unbalanced 95% PV penetration & PF=0.9

As PV penetrations approach 100% with all customers connecting an average of 5kVA upgrades to LV circuits will often be necessary.

Study 2: Semi-Rural Network – 1 Phase Inverter, End of LV Circuit

Modelling the LV network with a 200 kVA transformer, 60 customers with ADLD of 0.5 kVA, LV conductor of 7/.080 Copper, has found that when a 1x10 kVA single phase inverter is connected 400 metres from the transformer, the voltage can rise from 243 V at the transformer to 269 volts at 400 metres (a 10.2% rise as shown in Figure B10).

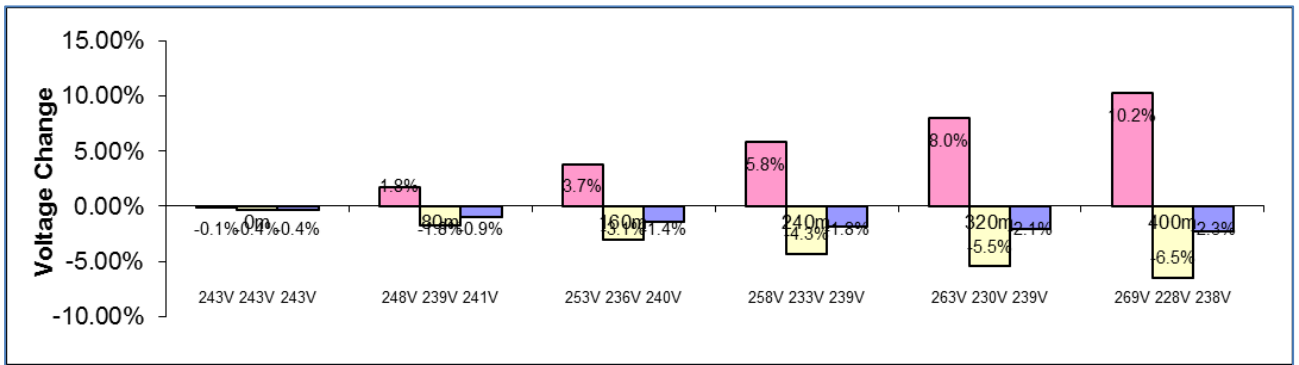


Figure B10 – Voltage rise on LV network with 1 x 10 kVA inverter installed 400 metres from transformer

Study 3: Semi-Rural Network – 3 Phase Inverter, End of LV Circuit

Similar LV model to Study 2 but with 3 x 10 kVA inverters installed shows a voltage rise of only 11 volts (or 4.4% as shown in Figure B11) highlighting the reduction in voltage rise from balanced systems due to the reduction in neutral current. As a rule of thumb connecting the same size IES on three phases will result in about 1/6th the voltage rise of a single phase system.

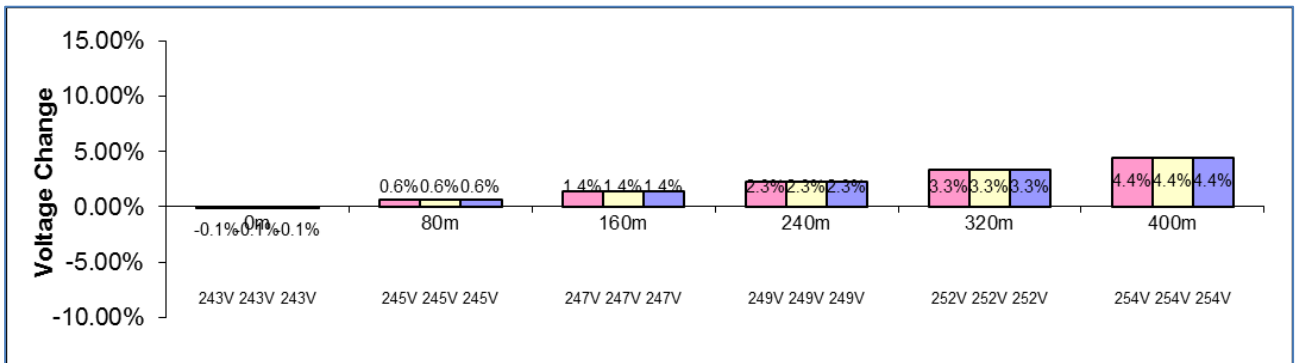


Figure B11 – Voltage rise on LV network with 3 x 10 kVA inverters installed 400 metres from transformer

Study 4: Semi-Rural Network – 1 Phase Inverter, End of LV Circuit; Reconductor

Similar LV model to Study 2 but with LV conductor replaced with LVABC shows a reduction in voltage rise to 12 volts (or 4.4% as shown in Figure B12)

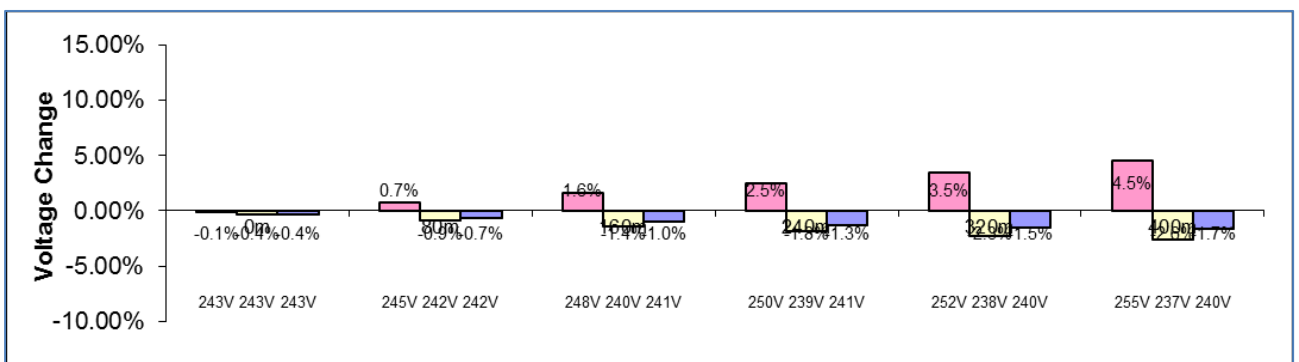


Figure B12 – Voltage rise on LVABC network with 1 x 10 kVA inverter installed 400 metres from transformer

APPENDIX C: New Connections Assessment Process

21 April 2015

Connection of Inverter Energy Systems to the Energex Network (up to 30kVA)

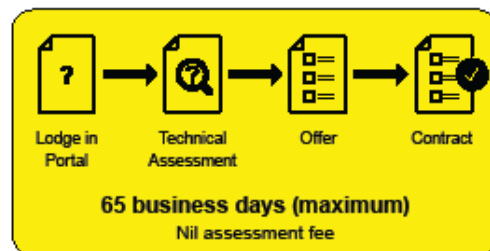
Inverter total capacity

The total capacity of your system, and your plans for exporting excess energy back into the network, will affect the assessment process undertaken by Energex.

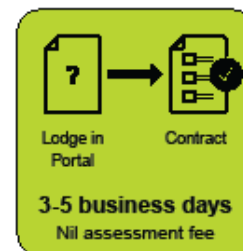
Inverter Total Capacity (kVA)	Export 1 or 2 Phase	Export 3 Phase	Nil Export
0	AS4777 Compliant Inverter	AS4777 Compliant Inverter	
3	AS4777 Compliant Inverter Reactive Power Control	AS4777 Compliant Inverter Reactive Power Control	AS4777 Compliant Inverter 1, 2 or 3 phase Power Limiting Device
5	AS4777 Compliant Inverter Reactive Power Control 2 phase	AS4777 Compliant Inverter Reactive Power Control	AS4777 Compliant Inverter 2 or 3 phase Power Limiting Device
10		AS4777 Compliant Inverter Reactive Power Control	AS4777 Compliant Inverter 3 phase Power Limiting Device
15		AS4777 Compliant Inverter Reactive Power Control	AS4777 Compliant Inverter 3 phase Power Limiting Device
30		AS4777 Compliant Inverter Reactive Power Control	AS4777 Compliant Inverter 3 phase Power Limiting Device

■ Manual Assessment ■ Automated Assessment

Manual Assessment



Automated Assessment



Reactive Power Control – Inverter set to 0.9 power factor lagging/underexcited

Power limiting device – as defined in Energex Standard 1143, limits export power to max 2 per cent inverter capacity, 10 second delay.

Manual contract agreement

Once lodged, this application may take up to 65 business days (maximum under NECF) to process and results in a physical offer being presented to the customer with the need for a signature on the agreed contract.

Automatic contract agreement

A deemed contract is formed when the customer accepts the standard conditions of contract and no further information is required from the customer. This process may take up to five business days.

For further information – refer to Energex Connection Standard 1143 at:
<https://www.energex.com.au/contractors-and-service-providers/solar-pv-installers/new-inverter-energy-systems-ies-connection-standard>

