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Distributed Energy Resources Enablement Project – Problem Statement Paper

Prepared for Renew

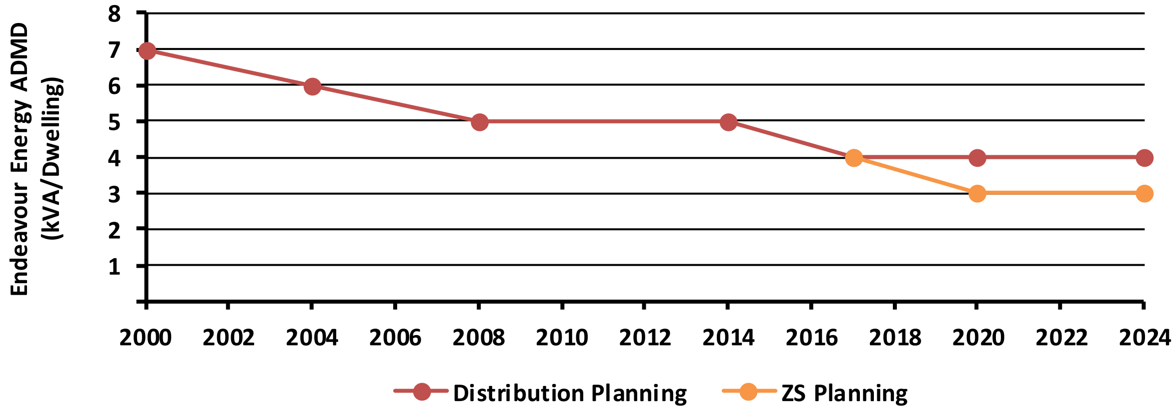
10 January 2020

ENERGEIA

Executive Summary

Electricity distribution networks were originally designed and built to accommodate around 1 kW of After Diversity Maximum Demand (ADMD) per residential premise. Over the past 50 years or so, an increase in the number and nature of loads in the home, particularly air-conditioners (ACs), has resulted in distribution network planners assuming up to 7 kW ADMD for new residential premises[1] in the early 2000s. However, over the past two decades, improvements in building standards, decreases in average building size, solar penetration and increasingly efficient home appliances have brought the ADMD back down to 4 kW, as shown below.

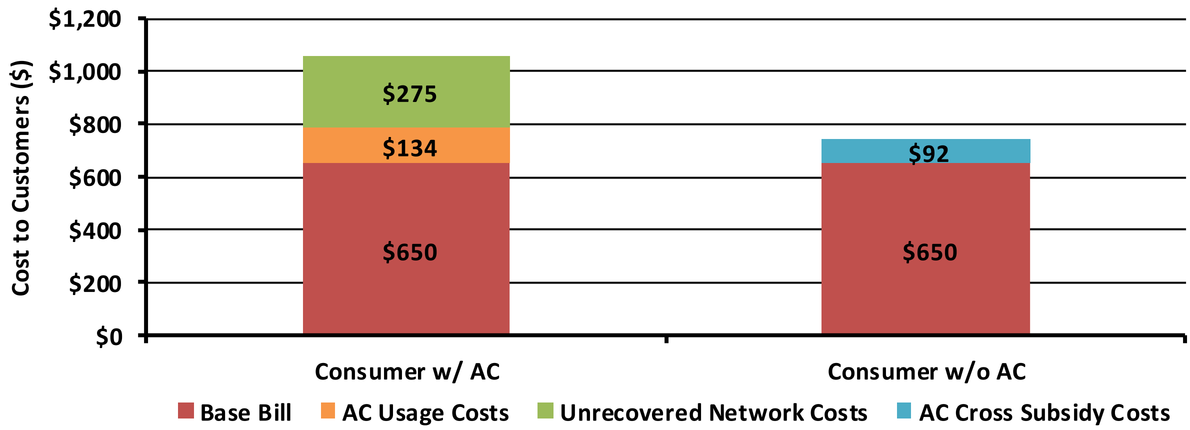
Endeavour's Historic ADMD



Source: Endeavour[1]

ACs are widely believed to be a key driver of the increase in ADMD and associated power quality issues, the higher costs have not been specifically allocated to those with these devices. The lack of an effective 'cost-reflective' pricing system, at least not for existing premises, has led to an uneconomic increase in network capital expenditure over the past 10-15 years. While those with ACs do pay more due to the higher energy consumption of these devices, non-cost reflective pricing resulted in significant cross-subsidies[2].

Illustration of Residential Bill Impacts from AC Adoption by AC Adoption Status



Source: Energeia; Note: AC = Air-Conditioners

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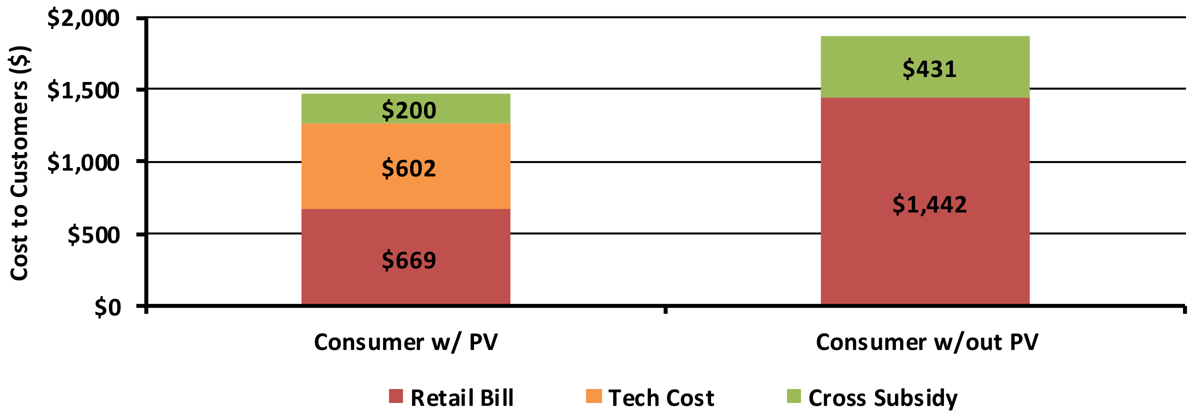
[1] Endeavour (2018), '*Regulatory Proposal*', https://www.aer.gov.au/system/files/Endeavour%20Energy%20-%200.01%20Regulatory%20Proposal%20-%20April%202018%20-%20Public.pdf

[2] It is worth noting that cross-subsidies are an inherent part of the energy system, and that is by design (e.g. urban customers cross-subsidising rural ones). The key issue is ensuring that the cross-subsidy is equitable. Some level of cross subsidy is accepted due to the transaction cost of unwinding them. For example, charging every dwelling based on their exact cost-to-serve would result in no cross-subsidies, but would be extremely complex and costly to calculate, uniformly increasing customer bills.

Rooftop solar photovoltaic (PV) systems are the latest change in customers' use of the electricity distribution network. Their penetration has risen rapidly over the past 5-10 years, and Australia now has among the highest penetration of rooftop solar PV in the world. Solar PV, as was the case with AC before it, is widely believed to be a key driver of emerging thermal constraints and power quality issues, and increasing cross-subsidies between those able to install a solar PV system and those that can't, typically those renting and/or living in apartments.

Illustration of Residential Bill Impacts from PV Adoption by PV Adoption Status



Source: Energeia

Distribution Network Service Providers (DNSP) response to rising solar PV penetration and associated grid and inverter impacts has been to limit the size of new solar PV systems connecting to their network, and to disallow new solar PV system connections in some cases. It is important to note that DNSP's current approach is at least partly due to the current National Electricity Rules that govern DSNP investment cost recovery, as they do not provide cost-recovery certainty for connecting generation to the distribution network.

Importantly, Australian DNSPs have started to look at better options[3] for integrating Distributed Energy Resources (DER) at lower cost, including solar PV, battery storage and electric vehicles. The approaches being proposed by DNSPs in their submissions to the Australian Energy Regulator (AER) come at a significant cost[4], and it is therefore critical that the approach ultimately adopted is in the best interests of all Australians. It is also important that the associated costs and benefits be equitably distributed among stakeholders.

Scope and Approach

As a community organisation interested in the fair treatment of solar PV and other DER technologies, Renew engaged Energeia to help inform the national debate regarding rooftop solar PV and other DER by:

- Identifying the key issues related to rising solar PV and DER and who they impact;
- Identifying the potential solutions to these issues and their associated cost; and
- Developing an analytical framework for identifying the optimal approach in a given situation.

Energeia developed the following approach to address Renew's key objectives and scope of work based on our experience modelling and optimising DER net benefits over the past ten years:

- **Comprehensive desktop review of key industry and academic reports** – The desktop review focused on reported issues and solutions. It included submissions to the Australian Energy Regulator (AER) and Distribution Annual Planning Reports (DAPR), as well as major international studies.

[3] See Energex (2018), 'Distribution Annual Planning Report', https://www.energex.com.au/__data/assets/pdf_file/0016/720223/Distribution-Annual-Planning-Report-2018.pdf and Ergon (2018), 'Distribution Annual Planning Report', https://www.ergon.com.au/__data/assets/pdf_file/0018/720234/DAPR-2018-2023.pdf

[4] Ibid.

- **Short listing of the key issues, solutions and development of an optimisation framework** – Energeia engaged with the stakeholder represented Steering Committee to validate the key issues, solutions and optimisation framework; however, the final list and approach is ultimately our own view.
- **Documentation of our key findings and engaging with stakeholders** – Energeia developed this Stage 1 Report for wider consultation with key stakeholders. The feedback from this report will be used to refine the optimisation framework and key issue and solution inputs.

The next step in the project involves the finalisation and implementation of the optimisation framework, and documentation of the results in a subsequent Stage 2 Report.

Stage 1 – Research Key Findings

Key DER Integration Issues

Energeia completed a comprehensive desktop research process, including the low voltage (LV) network management and DER connection practices of all 13 DNSPs in the National Electricity Market (NEM), and major international studies in Europe and North America. Our research totalled tens of thousands of pages over 130 key documents, which are summarised in the bibliography (Appendix A).

Energeia's comprehensive review of the issues reported to be associated with increasing rooftop solar PV adoption identified 21 key issues, 11 of which were distribution network impacts as shown in the table below. Issues were selected based on their expected total cost over time.

Summary of Issues Associated with Rising DER Penetration

Stakeholder	Category	Issue	Impacts
Customers with Solar PV	Investment	Connection Limits	Connection standards can limit efficient investment choices in DER
		Export Limits	Connection standards can limit efficient operation of DER
		Inverter Curtailment	Inverter standards can reduce output and investment certainty
		Increased Energy Losses	Inverter standards can increase reactive power losses, reducing investment certainty
		Reduced Capacity	Inverter standards can increase reactive power, reducing inverter capacity and investment certainty
		Reduced Lifetime	Inverter standards can increase reactive power, reducing inverter lifetime, impacting investment certainty
Distribution Networks	Power Quality	Over-Voltage	Excess generation can increase voltage above allowed thresholds
		Under-Voltage	Generation can increase voltage range, leading to under-voltage
		Flicker	Intermittent generation can lead to voltage flicker
		Harmonics (THD)	Inverters can inject additional harmonics
	Reliability	Thermal Overload	Generation levels can exceed thermal rating limit
	Safety	Protection Maloperation	Changes in generation and load patterns can break some schemes
		Islanding	Inverters can fail to disconnect, creating safety issue
	System Security	Disturbance Ride-through	Inverters disconnect during disturbance, worsening the disturbance
		Under Frequency Shedding	Load shedding inverters can increase net load, worsening frequency
	Cost / Efficiency	Phase Imbalance	Inverters can be unevenly distributed, unbalancing the g rid
		Forecasting Error	Stochastic inverter uptake and output can reduce forecast accuracy
Generation, Transmission and Market Operations	Operability	Ramp Rate	Inverters can increase rate of change above system capabilities
	Reliability	Thermal Constraints	Large DER resources can overload thermal limits
	Safety	Fault Levels	Inverters can reduce fault current
	Cost / Efficiency	Forecasting Error	Uptake and operation can increase forecasting error
		Generation Curtailment	Curtailment of DER generation can increase wholesale market prices

Source: Energeia; Note: THD = Total Harmonic Distortion, Grey indicates that issue is addressed by current inverter standards.

Key DER Integration Solutions

Energeia's comprehensive review of the potential solutions to the identified key issues identified 22 key options, grouped into six categories:

- **Customers** – Customer-side solutions include load change, and/or DER investment and/or DER operation
- **Pricing Signals** – Improved cost and value signalling, from moving to basic Time-of-Use pricing to establishing the most sophisticated, real-time and locational signals possible
- **Technical Standards** – Changes to both inverter (i.e. so-called 'smart' inverter standards and remotely configurable inverters) and connection limits standards (dynamic limits replacing static limits)
- **Reconfiguration** – Changing existing settings, topology, schemes and operation of the LV network to remediate identified issues (excludes investment in new methods or assets)
- **New Methods** – New methods or techniques for resolving issues, such as improved forecasting methods and use of non-traditional data sources including third party inverters and smart meters
- **New Assets** – New monitoring, control, voltage regulation, transformer or conductor assets to remediate identified issues

Question 1. Do you agree that the above represents the key issues related to rising DER penetration based on total cost, including opportunity cost? If not, please identify your proposed changes and the supporting evidence for the changes.

Solution to Issue Mapping

Each solution can potentially remediate multiple issues. Based on our research, Energeia mapped each solution to each identified issue, with the resulting impact assessment reported in the table below.

Summary Mapping of Remediation Options to DER Issues

Issue Stakeholder	Key Issue	Potential Solutions					
		Customers	Pricing Signals	Technical Standards	Re-configuration	New Methods	New Assets
Prosumer	Investment	✓	✓	✓*	✓*	✓*	✓*
Distribution Network Service Providers	Power Quality	✓	✓	✓*	✓*	✓*	✓*
	Reliability	✓	✓	✓*	✓*	✗	✓*
	Safety	✗	✗	✓*	✓*	✗	✓*
	System Security	✓*	✗	✓*	✓*	✓*	✓*
	Cost / Efficiency	✓	✓	✓*	✓*	✓*	✓*
Gen, Tx and Mkt Ops	Various	✓*	✓*	✓*	✓*	✓*	✓*

Source: Energeia; Note: Gen = Generation; Tx = Transmission; Mkt Ops = Market Operations;
✓ = Full Match (i.e. all of the potential solutions match all of the identified issues in these categories);
✓* = Partial Match (i.e. some potential solutions match some of the identified issues in these categories);
✗ = No Matches (i.e. none of the potential solutions match any of the identified issues).

Question 2. Do you agree that the above represents the key solution options to the key issues, and that the mapping of solutions to options is correct? If not, please identify your proposed changes and the supporting evidence for the changes.

Solution Costs

Energeia used desktop research, consultation with the Steering Committee, and our industry network to develop indicative cost estimates for each of the key solutions, as shown in the table below.

Summary of Key Solution Cost Estimates by Category

<table>
<tr><th>Category</th><th colspan="2">Solution</th><th>Capex</th><th>Opex</th><th>Units</th></tr>
<tr><td rowspan="3">Consumer</td><td colspan="2">Water Heater Management – Controlling Existing</td><td>$150</td><td>$15</td><td>kW</td></tr>
<tr><td colspan="2">Pool Pump Management - Controlling Existing</td><td>$50</td><td>$15</td><td>kW</td></tr>
<tr><td colspan="2">Storage Management - Controlling Existing</td><td>$50</td><td>$15</td><td>kW</td></tr>
<tr><td>Pricing</td><td colspan="2">Coarse (e.g. ToU pricing), excl. smart meter</td><td>Negligible</td><td>$0</td><td>Customer</td></tr>
<tr><td>Signals</td><td colspan="2">Granular (e.g. real-time pricing), excl. smart meter</td><td>$12m</td><td>$250k</td><td>DNSP</td></tr>
<tr><td rowspan="4">Technical Standards</td><td colspan="2">Inverter Standards</td><td>Negligible</td><td>$0</td><td>DNSP</td></tr>
<tr><td colspan="2">Remote Inverter Configuration</td><td>Negligible</td><td>$0</td><td>Country</td></tr>
<tr><td colspan="2">Static Limitations</td><td>Negligible</td><td>$0</td><td>DSNP</td></tr>
<tr><td colspan="2">Dynamic Limitations</td><td>$6m</td><td>$250k</td><td>DNSP</td></tr>
<tr><td rowspan="5">Reconfiguration</td><td colspan="2">Change Taps</td><td>Negligible</td><td>$1-2k</td><td>Trip</td></tr>
<tr><td colspan="2">Change Topology</td><td>$200k-$660k</td><td>$0</td><td>Feeder</td></tr>
<tr><td colspan="2">Change UFLS</td><td>$100k-$150k</td><td>$0</td><td>Feeder</td></tr>
<tr><td colspan="2">Change Protection</td><td>$1,000</td><td>$0</td><td>Feeder</td></tr>
<tr><td colspan="2">Balance Phases</td><td>Negligible</td><td>$1.5-$2k</td><td>Trip</td></tr>
<tr><td rowspan="3">New Methods</td><td rowspan="2">Third Party Data</td><td>New Install</td><td>$500</td><td>$5</td><td>Customer</td></tr>
<tr><td>Previous Install</td><td>Negligible</td><td>$5</td><td>Customer</td></tr>
<tr><td colspan="2">Better Long – Term Forecasts</td><td>$8m</td><td>$250k</td><td>DSNP</td></tr>
<tr><td rowspan="8">New Assets</td><td colspan="2">LV Metering</td><td>$3,500</td><td>$30</td><td>Transformer</td></tr>
<tr><td colspan="2">Voltage Regulators</td><td>$300,000</td><td>2.5% of capex</td><td>Regulator</td></tr>
<tr><td colspan="2">Larger Assets</td><td>$100k-$400k</td><td>2.5% of capex</td><td>Asset</td></tr>
<tr><td rowspan="2">On-Load Tap Changer</td><td>Vault</td><td>$120k</td><td>$7k</td><td>Transformer</td></tr>
<tr><td>Pole-Mounted</td><td>$60k</td><td>$7k</td><td>Transformer</td></tr>
<tr><td colspan="2">Harmonic Filters</td><td>$500k</td><td>$0</td><td>Substation</td></tr>
<tr><td colspan="2">Statcom (Single-Phase)</td><td>$5-8k</td><td>2.5% of capex</td><td>LV Phase</td></tr>
<tr><td colspan="2">Network Storage</td><td>$550</td><td>2.5% of capex</td><td>kWh</td></tr>
</table>

Source: Energeia;
Notes: 1. Changes deemed to be part of existing operations excluded, e.g. introduction of new price structures. 2. In-depth consultation with DNSPs would be required on to better understand costs on a jurisdictional basis.

The indicative costs above will be taken forward into the indicative cost-benefit and optimisation analysis conducted in Stage 2. Energeia recognises that solution costs can vary widely according to numerous factors including network density and topography. These costs are intended to be indicative, high level estimates, and do not necessarily reflect the views of all Steering Committee members.

Question 3. Do you agree that the proposed solution costs are reasonably accurate? If not, please provide alternative cost estimates, and the evidence for their accuracy.

Stage 2 – DER Integration Optimisation

In our Stage 2 paper, Energeia will implement the framework and approach proposed below to analyse and optimise the identified issues and proposed solutions across key LV network archetypes. Importantly, the framework is not intended to be used as a definitive framework or solution for any specific network. Rather, it is intended to identify the key issues and solutions and their indicative marginal costs.

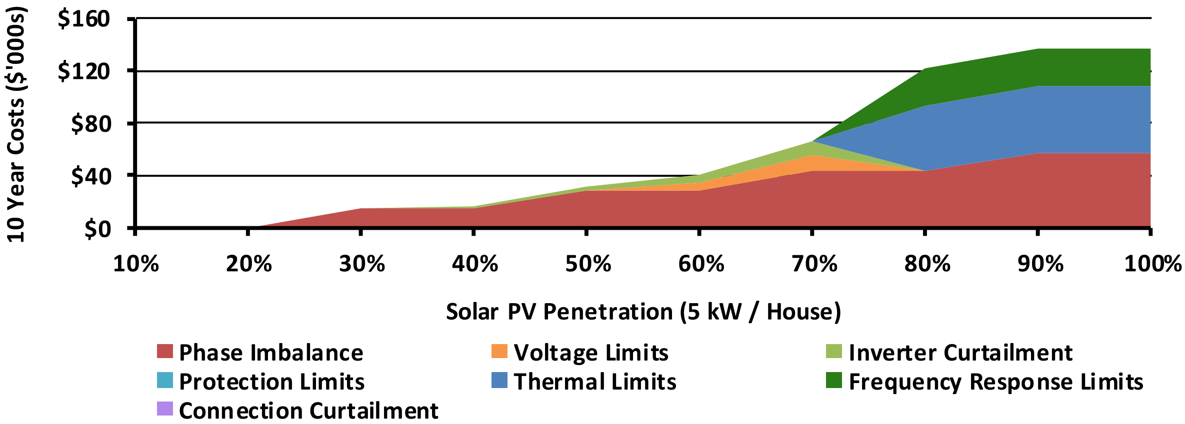
Feedback is requested regarding the proposed modelling approach and key inputs.

DER Integration Cost Modelling Approach

Energeia developed a high level, best practice DER-integration optimisation framework based on our research of best practice approaches to DER integration solution optimisation, and our experience modelling the costs and benefits of DER across consumers, prosumers, DNSPs and the wholesale market.

An illustration of the estimated remediation cost of the current industry integration solution for a given LV network type (urban overhead, 200 kVA transformer) under a given scenario (moderate DER growth) is shown in the figure below. This example identifies the estimated costs across identified issue categories, by solar PV penetration level.

Illustration of Overhead, Urban LV Network Integration Solution Costs by Inverter Penetration Level



Source: Energeia,
Notes: 1. Transparent colours (i.e. Inverter Curtailment) indicates cost of solution is borne by consumers rather than by DNSPs

Question 4. Do you agree that the proposed approach to modelling DER integration costs is reasonable for the intended purpose? If not, please identify an alternative approach and provide evidence for it being an improvement to the proposed approach.

To implement the proposed approach, Energeia will need to develop a number of key inputs including issue and solution costs, cost driver scenarios, solution phasing, and an LV network classification approach.

Key LV Network Categories

Based on our research of best practice LV hosting capacity analysis, and our experience estimating hosting capacity in Australia and overseas, Energeia is proposing to model the key network types in the table below.
Summary of Proposed LV Network Classifications

Name	Customer Mix	Reliability Type	Construction
Res, Urban, Overhead	Res	Urban	Overhead
C&I, Urban, Overhead	C&I	Urban	Overhead
Res, Urban, Underground	Res	Urban	Underground
C&I, Urban, Underground	C&I	Urban	Underground
Res, Rural, Overhead	Res	Rural	Overhead
C&I, Rural, Overhead	C&I	Rural	Overhead

Source: Energeia; Note: C&I = Commercial and Industrial, Res = Residential

We have excluded CBD and underground rural types as being relatively immaterial.

Question 5. Do you agree with the key LV network types proposed are reasonable? If not, please provide alternative LV network categories, and the evidence supporting their use.

Key Cost Driver Uncertainties

Energeia proposes to use scenarios to model the potential range of key DER integration costs drivers over time. The key DER integration cost drivers proposed to vary by scenario include wholesale, retail, network and DER integration technology prices. These price drivers will in turn impact on customer DER adoption levels, which will impact on the timing of DER integration issues and the availability of DER for their remediation. Energeia's solution cost assumptions are shown in the table below.

Draft Scenario Design Framework

Driver Category	Scenario Drivers	Scenario Theme: Decentralised	Scenario Theme: Expected	Scenario Theme: Centralised
Technology Costs	Storage Costs	To be completed in Stage 2		
	Solar PV Costs			
	VPP Costs			
	LMP/DSO/etc. Costs			
Energy Costs	PV Weighted NEM Prices			
	Retail Electricity Prices			
Bulk System Costs	Ramping Prices			
	Flexible Prices			
Network Costs	LRMC			
	Tariff Reforms			
Customer Behaviour	Solar PV Adoption			
	Storage Adoption			
	EV Adoption			
	VPP/Peer-to-Peer Adoption			
	Gas Appliance Electrification			

Source: Energeia

Energeia will develop and agree scenario themes and driver settings with Renew prior to implementing them in the modelling.

Question 6. Do you agree that the DER integration cost drivers proposed for the scenario modelling are reasonable? If not, please provide alternative key cost drivers, and the evidence supporting their inclusion.

Next Steps

Please send your comments to Dean Lombard at Renew (dean.lombard@renew.org.au) by the 15 February 2020 for consideration in our Stage 2 report, due out in early 2020.

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Disclaimer

While all due care has been taken in the preparation of this report, in reaching its conclusions Energeia has relied upon information and guidance from Alternative Technology Association (trading as Renew), and other publicly available information. To the extent these reliances have been made, Energeia does not guarantee nor warrant the accuracy of this report. Furthermore, neither Energeia nor its Directors or employees will accept liability for any losses related to this report arising from these reliances. While this report may be made available to the public, no third party should use or rely on the report for any purpose.

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1. Background to the Project

Customer applications for the electricity system (the grid) have evolved over time with the introduction and deployment of new technologies. In addition to whether and how to charge for connection and using new devices, there is typically a discussion regarding whether there are more efficient methods for its integration. The tradition to date has been socialisation of the cost across all system users, and industry effort to minimise costs.

The rapid rise of rooftop solar photovoltaic (PV) adoption over the last decade is the latest 'new' grid application, and there is debate regarding how and whether to regulate and price it. Also included in the current debate is the optimal approach to integrating solar PV and other inverter based, consumer-side devices, including battery storage and electric vehicles into the distribution network and power system.

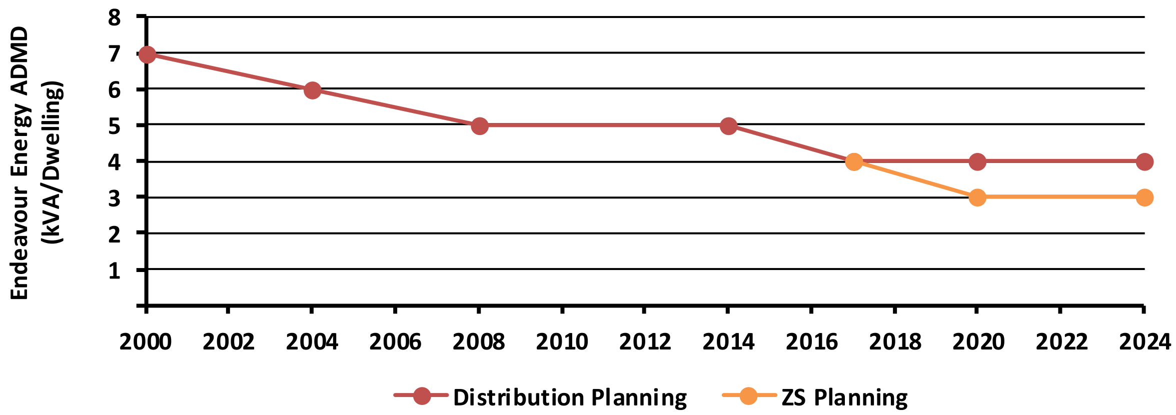
The following sections summarise the following:

- The historical debate regarding new applications like reverse cycle air-conditioners (ACs),
- The current state of solar PV adoption and estimated impacts, and
- The current industry initiatives underway to minimise system adaptation costs (technically called 'integration' costs) and to potentially allocate them to solar PV owners and adopters of other 'new' devices connected to the electricity distribution system.

1.1. Trends in Electricity System Applications

Electricity distribution networks were originally designed and built to accommodate around 1 kW of After Diversity Maximum Demand (ADMD) per residential premise. Over the past 50 years or so, an increase in the number and nature of loads in the home, particularly air-conditioners (ACs), has resulted in distribution network planners assuming up to 7 kW ADMD for new residential premises[5] in the early 2000s. However, over the past two decades, improvements in building standards, decreases in average building size, solar penetration and increasingly efficient home appliances have brought the ADMD back down to 4 kW, as shown in Figure 2.

Figure 1 – Endeavour's Historic ADMD



Source: Endeavour[1]

1.1.1. Air-Conditioners

ACs are widely believed to be a key driver of the increase in ADMD and associated power quality issues, the higher costs have not been specifically allocated to those with these devices. The lack of an effective 'cost-reflective' pricing system, at least not for existing premises, has led to an uneconomic increase in network capital

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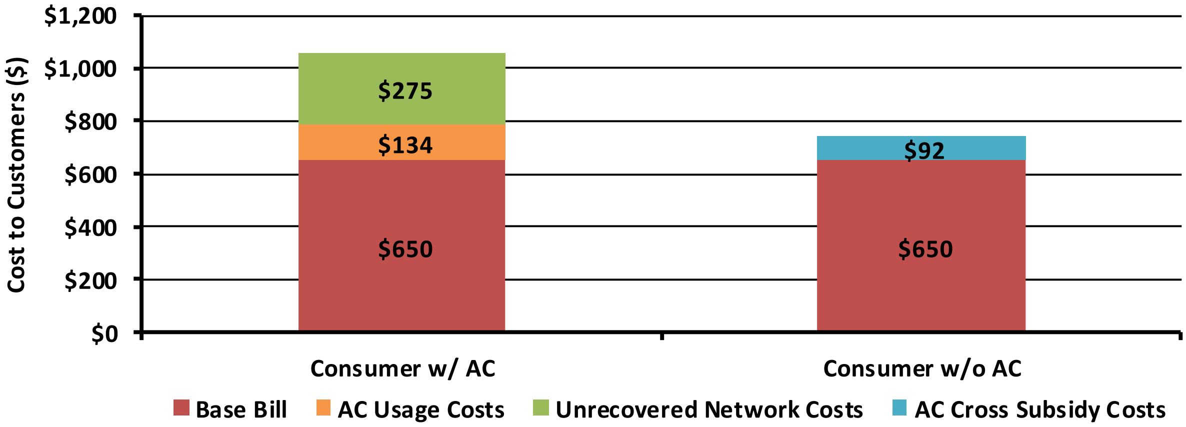
[5] Endeavour (2018), '*Regulatory Proposal*', https://www.aer.gov.au/system/files/Endeavour%20Energy%20-%200.01%20Regulatory%20Proposal%20-%20April%202018%20-%20Public.pdf

expenditure over the past 10-15 years. While those with ACs do pay more due to the higher energy consumption of these devices, non-cost reflective pricing resulted in significant cross-subsidies[6], as shown in Figure 2.

Figure 2 – Illustration of Residential Bill Impacts from AC Adoption by AC Adoption Status



Source: Energeia; Note: AC = Air-Conditioners

1.1.2. Rooftop Solar PV

Rooftop solar photovoltaic (PV) systems are the latest change in customers' use of the electricity distribution network. Their penetration has risen rapidly over the past 5-10 years, and Australia now has among the highest penetration of rooftop solar PV in the world, as shown in Distribution Network Service Providers (DNSP) response to rising solar PV penetration and associated grid and inverter impacts has been to limit the size of new solar PV systems connecting to their network, and to disallow new solar PV system connections in some cases. It is important to note that DNSP's current approach is at least partly due to the current National Electricity Rules that govern DSNP investment cost recovery, as they do not provide cost-recovery certainty for connecting generation to the distribution network.

Importantly, Australian DNSPs have started to look at better options for integrating Distributed Energy Resources (DER) at lower cost, including solar PV, battery storage and electric vehicles. The approaches being proposed by DNSPs in their submissions to the Australian Energy Regulator (AER) come at a significant cost, and it is therefore critical that the community welfare-maximising approach is ultimately adopted. It is also important that the associated costs and benefits be equitably distributed among stakeholders.

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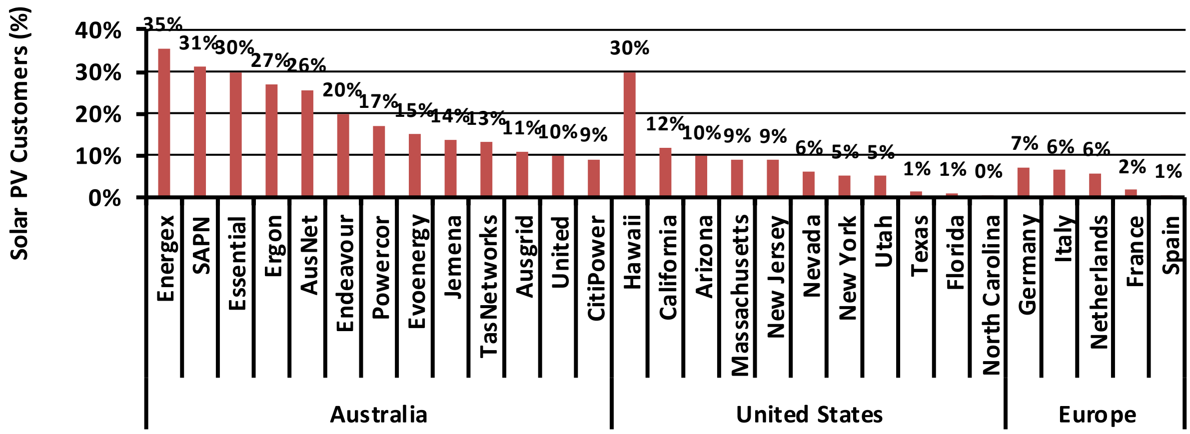
[6] It is worth noting that cross-subsidies are an inherent part of the energy system, and that is by design (e.g. urban customers cross-subsidising rural ones). The key issue is ensuring that the cross-subsidy is equitable. Some level of cross subsidy is accepted due to the transaction cost of unwinding them. For example, charging every dwelling based on their exact cost-to-serve would result in no cross-subsidies, but would be extremely complex and costly to calculate, uniformly increasing customer bills.

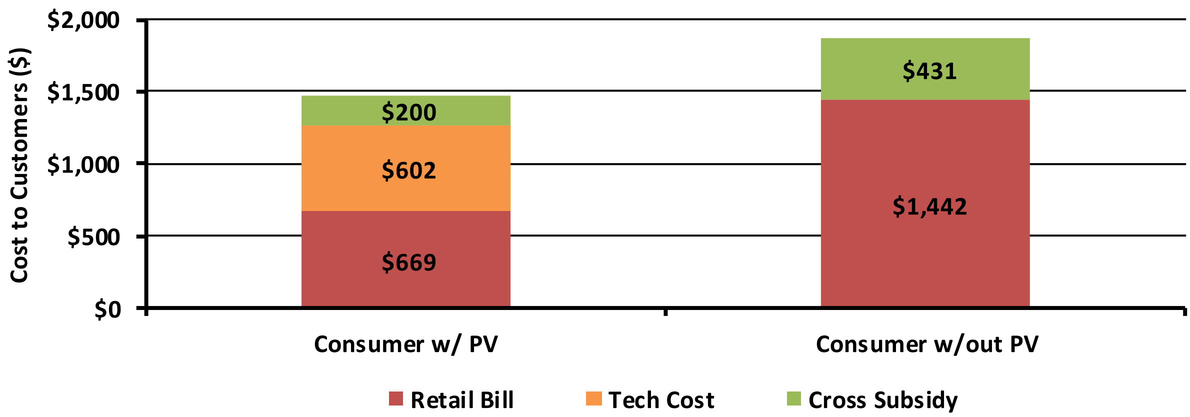
Figure 3 – Percentage of Solar PV Customers by DNSP



Source: Clean Energy Regulator, DNSP RINs, Energeia

Solar PV, as was the case with AC before it, is widely believed to be a key driver of emerging thermal constraints and power quality issues, and cross-subsidies between those able to install a solar PV system and those that can't, e.g. those renting and/or living in apartments. Figure 4 illustrates the typical level of annual cross-subsidy between a customer with solar PV and one without solar PV under current, flat or inclining block tariffs.

Figure 4 – Illustration of Residential Bill Impacts from PV Adoption by PV Adoption Status



Source: Energeia

As is the case with ACs via demand-side participation, solar PV systems can also potentially provide electricity system benefits, including lower wholesale prices, lower peak demand[7] and improve power quality. An example of how solar PV systems may be reducing peak demand on AusNet[8] and Endeavour Energy[9] zone substations is shown is Figure 5. Energeia notes the lack of a comprehensive assessment of solar PV net benefits to date.

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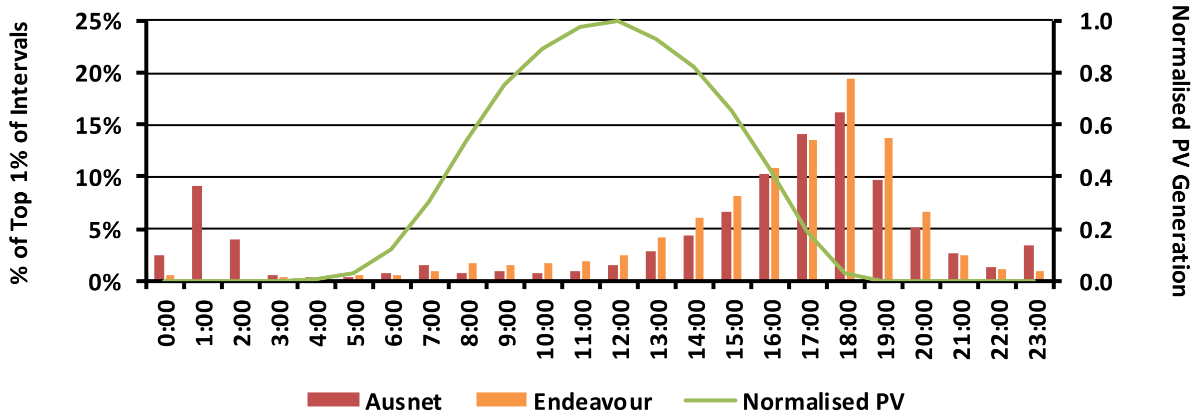
[7] Where peak demand coincides with PV generation.

[8] Ausnet zone-sub load profiles sourced from CSIRO EUDM

[9] Endeavour zone-sub load profiles sourced from Endeavour (2019), '*2018-19 Distribution zone substation data*', http://www.endeavourenergy.com.au/wps/wcm/connect/1875dfe1-6a62-4791-8eca-8dd1ada1a7b8/FY2018-19_CSV_2.zip?MOD=AJPERES&ContentCache=NONE

Figure 5 – Time-Distribution of Top 1% Zone-Sub Load Intervals vs. Solar PV Generation Curve



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Importantly, Australian DNSPs have started to look at better options[10] for integrating Distributed Energy Resources (DER) at lower cost, including solar PV, battery storage and electric vehicles. The approaches being proposed by DNSPs in their submissions to the Australian Energy Regulator (AER) come at a significant cost[11], and it is therefore critical that the community welfare-maximising approach is ultimately adopted. It is also important that the associated costs and benefits be equitably distributed among stakeholders.

1.1.3. Major New Device Outlook

While Australia is largely saturated in terms of ACs, rooftop solar PV growth remains strong, and behind-the-meter (BTM) storage and EV adoption is expected to soar in the next 10-20 years.

Solar and BTM storage forecasts commissioned by the market operator in 2019, as shown in Figure 6, expect a three to four fold increase in rooftop solar PV inverter capacity over the next 30 years. BTM storage is expected to rise between five to 20-fold over the same period in nameplate capacity terms.

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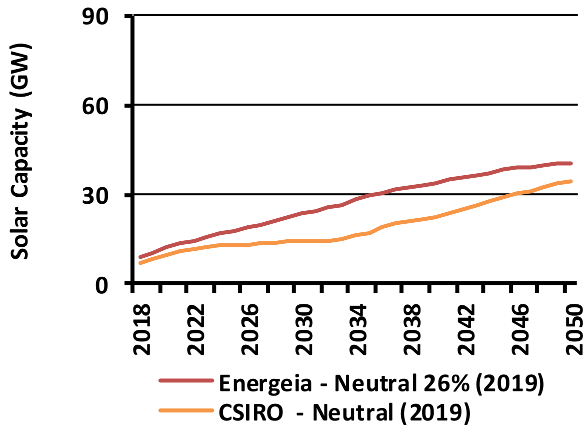
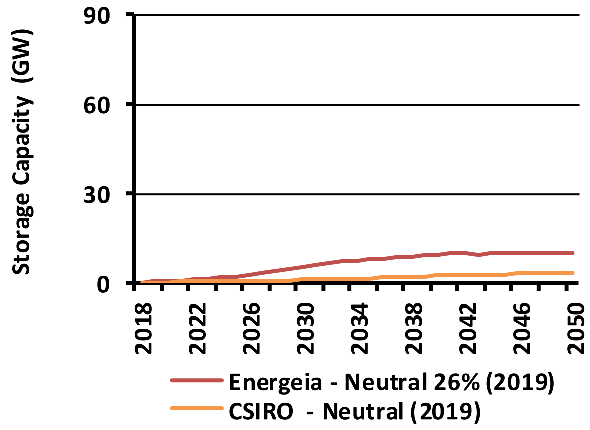
[10] See Energex (2018), 'Distribution Annual Planning Report', https://www.energex.com.au/__data/assets/pdf_file/0016/720223/Distribution-Annual-Planning-Report-2018.pdf and Ergon (2018), 'Distribution Annual Planning Report', https://www.ergon.com.au/__data/assets/pdf_file/0018/720234/DAPR-2018-2023.pdf

[11] Ibid.

Figure 6 – Rooftop Solar PV (Left) and Behind the Meter Storage (Right) Uptake (GW) Forecasts

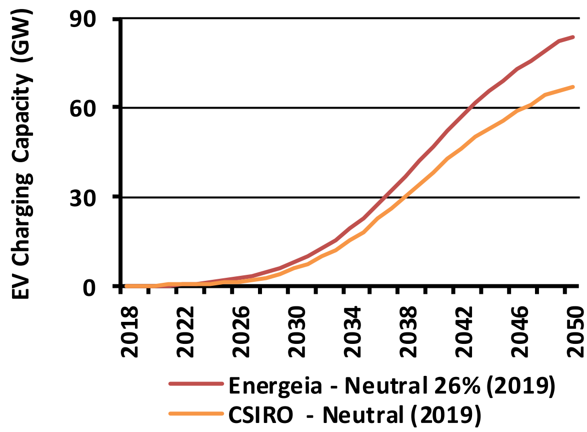


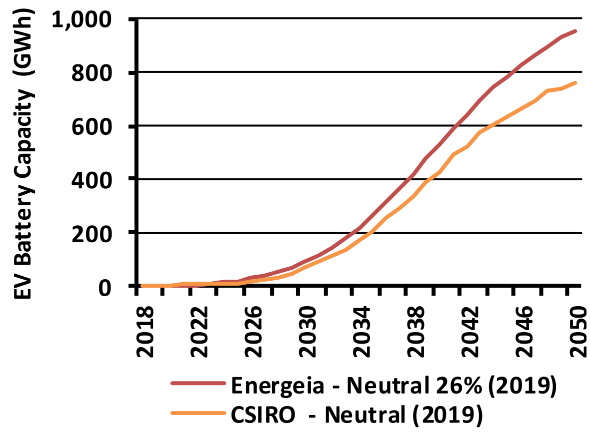


Source: Energeia, CSIRO; Note: Assumed 4-hour storage capacity

Although EV adoption is expected to remain largely flat until around 2025, it is expected to rise rapidly from that point onwards, reaching 9-11 million vehicles by 2050, or 80 GW in potential charging load and 950 GWh in total battery storage potential, dwarfing the stationary battery estimate as shown in Figure 7.

Figure 7 – Electric Vehicle Level 2 Charging Capacity (Left) and Battery Capacity (Right) Forecasts





Source: Energeia, CSIRO; Note: EV charging assumes avg. charger rating of 7.5kW. EV battery capacity assumes 85 kWh avg. battery.

Energeia estimates that each of the inverter based DER technologies discussed is expected to add the following level of nameplate demand to each residential premises:

- 5-8 kW of solar PV,
- 15-22.5 kW of Level 2 EV charging, and;
- 5-10 kW of battery storage.

Demand at commercial premises likely to be significantly higher.

As inverter-based equipment becomes the dominant type of grid connected technology at customer premises, it is critical that the proposed approach to pricing and managing them is fit-for-purpose.

1.2. Trends in LV Network Management

DNSPs have historically managed low voltage (LV) networks differently to the rest of the distribution network due to their sheer number of assets, and the relatively high cost of adding remote monitoring and control. They have typically been operated on a 'run-to-failure' basis, and reliant on customer reports of outages or voltage issues.

The rise of solar PV in the LV network is leading to a significant increase in customer reported issues, and an associated increase in the rate of LV network investment. As a result, DNSPs are re-assessing their LV management approaches, including limiting new connections and curtailing existing ones.

Key questions include whether the current or proposed future approaches will best serve Australians' overall interests, and whether there are any distributional effects that need to be considered to ensure fairness.

1.2.1. Changes in Key Connection and Technical Standards

The Australian electricity distribution and inverter industries, like their overseas peers, have implemented a number of key reforms over the past 3-5 years to their connection and other technical standards to address potential issues from rising rooftop solar PV capacity across their network.

New Static Solar PV Connection and Export Limits

A key DNSP response to date to potential issues related to solar PV penetration has been to set limits on solar PV capacity allowed to be connected to the network as shown in Table 1. Across the majority of DNSPs, the connection limit has been set to either 5 or 10 kW/kVA for a single-phase connection and up to 30 kW/kVA for a three-phase connection. Some DNSPs have stated explicit export limits lower than the connection limit.

Table 1 – Connection and Export Limits by DNSP and Phase

		Connection Limit		Export Limit	
State	**Network**	**Single Phase**	**Three Phase**	**Single Phase**	**Three Phase**
ACT	EvoEnergy	5kW	30kW	✓	✓
NSW	Ausgrid	10 kVA	30 kVA	N/S	N/S
	Essential	3 kW / 5 kW	30 kW	N/S	N/S
	Endeavour	8 kW	40 kW	5 kW	30 kW
QLD	Energex	10 kVA	30 kVA	5 kVA	30 kVA
	Ergon	10 kVA	30 kVA	5 kVA	30 kVA
SA	SAPN	10 kW	30 kW	5 kW	15 kW
TAS	TasNetworks	10 KW	30 kW	✓	✓
VIC	United	10 kW	30 kW	N/S	N/S
	CitiPower	5 kW	30 kW	N/S	N/S
	PowerCor	5 kW	30 kW	N/S	N/S
	Jemena	5 kVA	30 kVA	N/S	N/S
	Ausnet	10 kW	30 kW	3.5 kW / 5 kW	15 KW

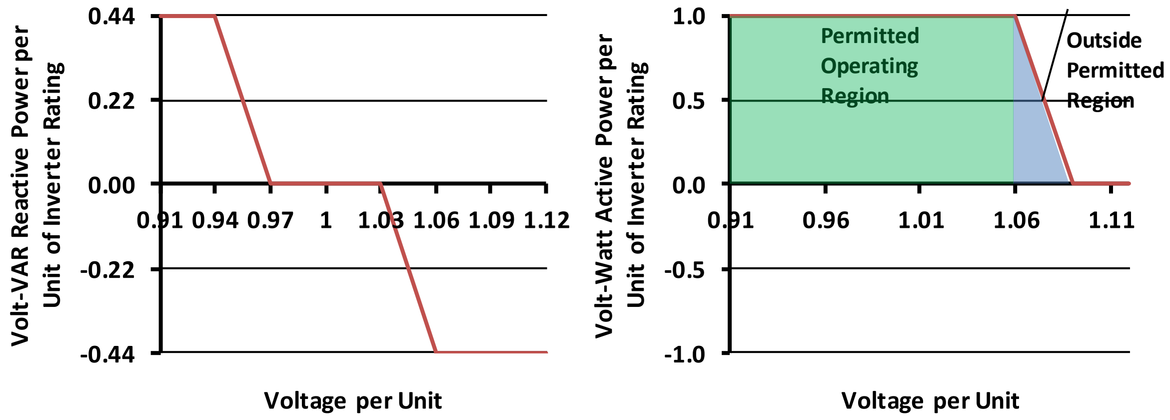
Source: DNSP Technical Standards
Notes: ✓ = explicitly stated that exports may be limited, N/S = not stated

Energeia has been unable to identify the original basis for the above limits, and recent work completed by SA Power Networks suggests that the actual solar PV hosting capacity varies widely by LV network type.

Modernised Inverter Standards

Australian industry stakeholders approved updates to AS4777 in 2015 that require inverters to curtail exports in response to voltage exceedances and grid outages. This is commonly known as the Volt-Watt standard, and Australia's current Volt-Watt setting is shown in Figure 8, along with the optional Volt-VAR setting.

Figure 8 – Volt-VAR and Volt-Watt Curves



Source: NREL, HECO[12]

Australian DNSP's are responsible for determining standard related specifics in their network, including whether or not the optional Volt-VAR standard is required, and if so, what the settings are.

Research has shown the Volt-VAR operating mode can enable up to around 60% penetration of solar PV systems without curtailment. However, it does not solve thermal issues, and inverter capacity is lost in proportion to reactive power generation[13]. Industry contacts report ~10% of current solar PV installations comply with Volt-VAR standards, indicating there may be an enforcement issue.[14]

More detail on current Australian standards for smart inverters and LV management are provided in Appendix C.

1.2.2. Emerging LV Management Issues

The two key issues that have emerged recently as rooftop solar PV penetration has risen are an increase in reported voltage issues, and its associated impact on rising levels of rooftop solar PV inverter curtailment.

Network Power Quality

There are increasing reports of distribution network voltages falling outside of their statutory limits, as shown in Figure 9. DNSPs are increasingly reporting customer enquiries and complaints related to solar PV voltage related issues, and indeed a range of networks (CitiPower, Powercor, SA Power Networks, AusNet and Jemena[15]) have proposed developing the ability to monitor and control solar PV exports to manage voltage exceedance.

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[12] NREL, HECO (2019), *'Impacts of Voltage-Based Grid-Support Functions on Energy Production of PV Customers'*: https://www.nrel.gov/docs/fy20osti/72701.pdf

[13] L. Ochoa, A. Procopiou, University of Melbourne (2019), *'Increasing PV Hosting Capacity: Smart Inverters and Storage'*: https://resourcecenter.ieee-pes.org/education/webinars/PESVIDWEBGPS0010.html

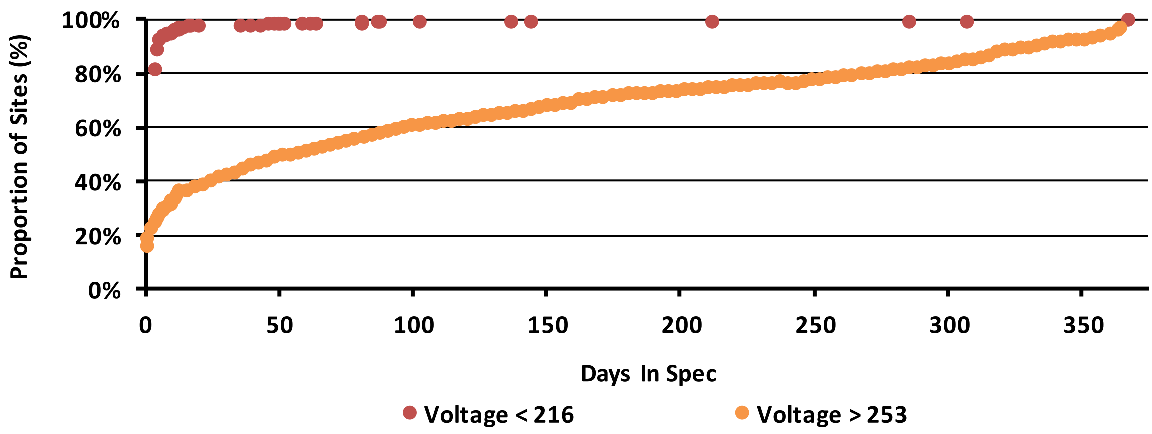
[14] Inverter standards compliance enforcement is a shared activity between DNSPs, jurisdictional regulators and bodies like the Clean Energy Council, which runs a voluntary industry scheme.

[15] CitiPower (2018), '*Distribution Annual Planning Report*': https://media.powercor.com.au/wp-content/uploads/2019/02/05081603/CitiPower-Distribution-Annual-Planning-Report-2018-final.pdf;

Jemena (2018), '*Distribution Annual Planning Report*': https://jemena.com.au/documents/electricity/jen-2018-dapr-v1-1.aspx

Powercor (2018), '*Distribution Annual Planning Report*': https://media.powercor.com.au/wp-content/uploads/2019/02/05081809/Powercor-Distribution-Annual-Planning-Report-2018-final.pdf

Figure 9 – Voltage Excursions (230V Standard)



Source: Solar Analytics[16]

Prosumer Curtailment

In Australia, there has been a limited range of either academic or industry work to define the DER hosting capacity of LV networks. Without this work being completed, DER capacity on a given network asset is unknown, but the existing limited work suggests that export curtailment will increase as DER penetration increases:

- **Smart Grid, Smart City (2014)**[17] – The Ausgrid managed project identified an increase in curtailment (i.e. the restriction of exports by DER investors) beyond 30% penetration.
- **University of Melbourne (2019)**[18] – Academics at the University of Melbourne have developed a stochastic approach that shows increasing curtailment from 10% penetration, based on a Monte Carlo analysis of a theoretical LV network in Australia, as shown in Figure 10.

The University of Melbourne's results appear to align with modelling results carried out by SA Power Networks[19] on the different areas in their network, which show some LV (but not all) network types experiencing voltage excursions (outside limits) at the 10% penetration limit.

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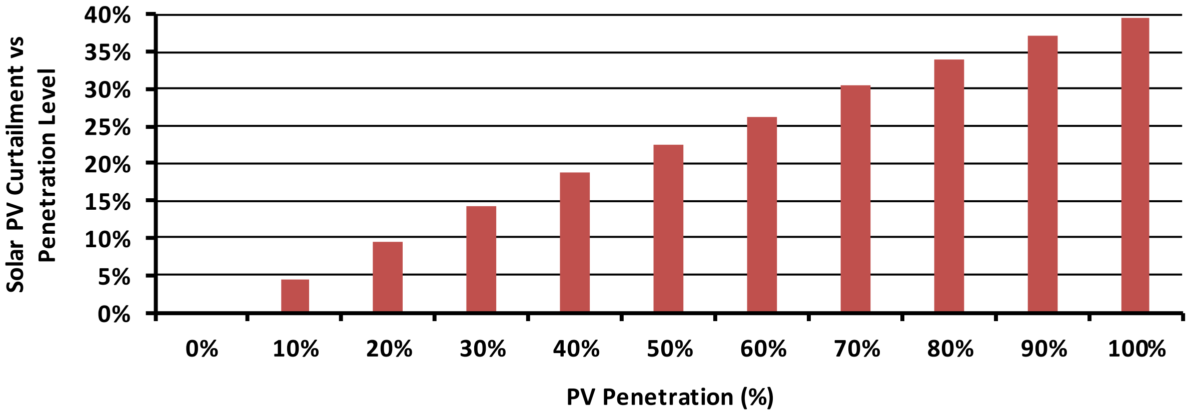
[16] Smart Energy Council (2019), *'Special Webinar: High Voltage is Stopping Solar – 5 September 2019':* *https://vimeo.com/357975007?utm_source=High+Voltage+Webinar+September+5th+2019&utm_campaign=d730815347-ECAMPAIGN_BrkgNews8Jul19_COPY_01&utm_medium=email&utm_term=0_67fc466c8e-d730815347-89547021*

[17] Archived version of the following source: Department of Industry, Innovation and Science (2016) 'Smart Grid, Smart City', https://webarchive.nla.gov.au/awa/20160615043539/http://www.industry.gov.au/Energy/Programmes/SmartGridSmartCity/Pages/default.aspx

[18] L. Ochoa, A. Procopiou, University of Melbourne (2019), *'Increasing PV Hosting Capacity: Smart Inverters and Storage'*: https://resourcecenter.ieee-pes.org/education/webinars/PESVIDWEBGPS0010.html

[19] SA Power Networks (2019), '*LV Management Business Case: 2020-2025 Regulatory Proposal'*: https://www.aer.gov.au/system/files/Attachment%205%20Part%207%20-%20Future%20Network.zip, pg. 6

Figure 10 – Solar PV Export Curtailment at Different Levels of Market Penetration

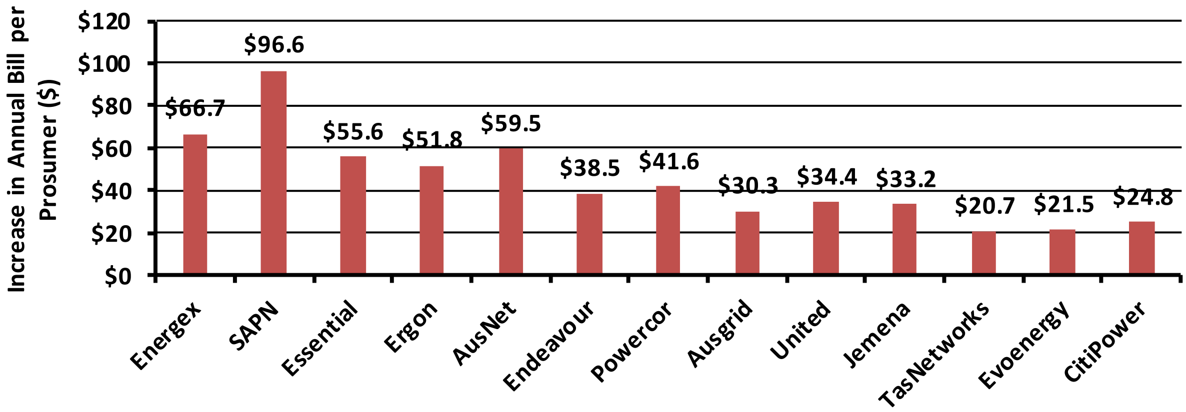


Source: IEEE / University of Melbourne[18]

1.2.3. Anticipated LV Management Costs

Energeia's estimate of annual losses to customers with solar PV due to losing feed-in tariff revenue from curtailment is shown Figure 11 by DNSP. The value of these losses will change over time as a result of changes in wholesale market regional reference prices, and changes to feed-in tariff policy.

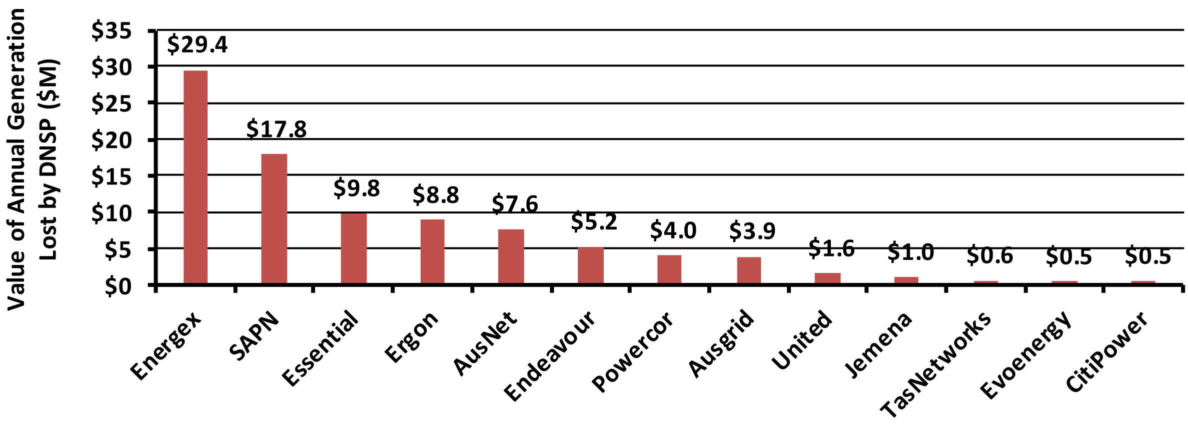
Figure 11 – Estimated DER Curtailment Costs per Customer with Solar PV



Source: Energeia;
Notes: SAPN = SA Power Networks

Energeia's analysis of the wholesale market value of annual curtailment losses to retailers are shown in Figure 11, based on current wholesale prices. This estimate does not consider any lost benefits from higher cost units setting the regional reference price in the National Electricity Market.

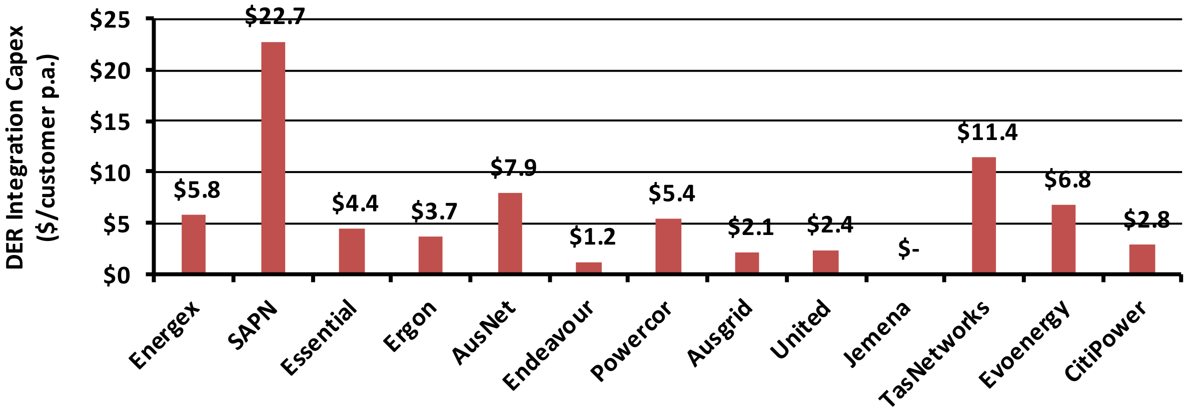
Figure 12 – Estimated ($M) Value of Annual Generation Lost to Curtailment by DNSP



Source: Energeia; Note: SAPN = SA Power Networks

The cost to DNSPs, and ultimately to Australian electricity consumers with and without solar PV, is also rising, with most DNSPs putting forward DER[20] integration costs of up to $23 per customer per annum as shown in Figure 13. Energeia notes that the proposed investment is targeted at accommodating forecast growth and reducing uneconomic curtailment.

Figure 13 – DNSP's Proposed DER Integration Expenditures ($/Customer/Year)



Source: DNSP Determinations; Note: PQ = Power Quality, SAPN = SA Power Networks

1.3. Key Distributed Energy Resource Integration Initiatives

A wide range of initiatives have been kicked off over the last 12 months to tackle the range of current issues associated with rising rooftop solar PV and other forms of DER, including the anticipated rise in related LV management and prosumer curtailment costs.

1.3.1. Key Regulatory and Industry-Led Initiatives

Australian stakeholder expectations regarding the impact of the rise of solar PV, storage and EV adoption over the next 20 years is triggering a number of industry initiatives to identify a range of DER integration solutions, from new technical standards, to new charges and new technical solutions, as listed in Table 2.

It is important to recognise that initiatives are being led by different National Electricity Market (NEM) bodies, such as the Australian Energy Market Operator (AEMO), the Australian Energy Market Commission (AEMC) and

[20] Not all expenditure is necessarily related to solar PV specifically

other prominent industry players, and therefore reflect incumbent agendas and perspectives. No consumer or prosumer led initiatives have been kicked off to date, nor are any currently being planned, limiting the voice of these stakeholders in the national debate to responding to other's initiatives.

Additional information regarding these initiatives is provided in Appendix C.

Table 2 – Current or Recent Distributed Energy Resources Management Initiatives

Initiative	Sponsor	Purpose and Objectives	Participants
Revision of AS 4777	Standards Australia	Sets out specifications, procedures and guidelines that aim to ensure products, services, and systems are safe, consistent, and reliable	Industry, consumers, and government
National Grid Connection Guidelines	ENA	Standardised guidelines for the connection of DER across the NEM (released September 2019)	Industry, consumers, and government
Distributed Energy Integration Program	ARENA	To maximize the value of customers' DER for all energy users	Industry, regulators, suppliers, government, and academia
Open Energy Networks	AEMO/ ENA	Consultation on how best to transition to a two-way grid that allows better integration of DER for the benefit of all customers	Industry, consumers, suppliers, government, and academia
Distributed Energy Resources Program	AEMO	To better utilise DER for the grid through developing and improving appropriate DER standards.	Industry, regulators, suppliers, government, and academia
Distribution Market Model	AEMC	To examine whether the economic regulatory framework is robust, flexible and continues to support the efficient operation of the energy market in the long-term interests of consumers	AER, ARENA, DNSPs, Standards Australia, and others

Source: Clean Energy Regulator, DNSP Regulations; Note: AEMC = Australian Energy Market Commission, AEMO = Australian Energy Market Operator, ARENA = Australian Renewable Agency, DER = Distributed Energy Resources, DNSPs = Distributed Network Service Providers, ENA = Energy Networks Australia.

1.3.2. Prosumer Focused, Collaborative Initiative Needed

Each of the above initiatives includes representatives from prosumer stakeholders, however, their role is limited to responding to the issues and questions determined by the sponsor. There is therefore a risk that the key issues and questions of greatest interest to prosumers have not yet been addressed. A prosumer led initiative may therefore be needed to ensure their perspective is truly represented in the national debate.

The types of issues and questions that a prosumer led initiative might ask (from a technical perspective) include:

- What is the fair and efficient level of curtailment and should there be compensation for curtailment?
- What is the fair and efficient level of DER connection capacity, and how might capacity rights be traded?
- Are the proposed DER integration solutions in the overall interest of Australians, and have all the options been considered, including those provided by consumers and prosumers?
- Have the benefits of DER been considered, with any shared benefits, for example from improvements in capex, opex or service level performance shared with prosumers and consumers?
- Are there any distributional effects from proposed DER integration solutions that need to be considered?

2. Scope and Approach

Renew engaged Energeia to review the range of issues related to solar PV, storage and EV adoption, the potential solutions for resolving them, including those potentially offered by consumer, prosumers and service providers, in order to identify the value maximising solution for Australia.

The project design envisioned:

- Identifying the key issues related to rising solar PV and DER and who they impact,
- Identifying the potential solutions to these issues and their associated cost,
- Developing an analytical framework for identifying the optimal approach in a given situation,
- Developing a report on the key issues and potential solutions (this report), for industry consultation,
- Developing a report on the optimal approach to a given situation, for industry consultation, and;
- Engaging with a stakeholder-rich Steering Committee convened by Renew, comprised of energy retailers, electricity DNSPs and DER services providers.

While critical to the discussion related to potential 'extra' charges for solar PV exports, the determination of solar PV net benefits is out of scope for this project.

- **Comprehensive desktop review of key industry and academic reports –** The desktop review focused on reported issues and solutions. It included submissions to the Australian Energy Regulator (AER) and Distribution Annual Planning Reports (DAPR), as well as major international studies.
- **Short listing of the key issues, solutions and development of an optimisation framework** – Energeia engaged with the stakeholder represented Steering Committee to validate the key issues, solutions and optimisation framework; however, the final list and approach is ultimately our own view.
- **Documentation of our key findings and engaging with stakeholders** – Energeia developed this Stage 1 Report for wider consultation with key stakeholders. The feedback from this report will be used to refine the optimisation framework and key issue and solution inputs.

The next step in the project involves the finalisation and implementation of the optimisation framework, and documentation of the results in a subsequent Stage 2 Report.

The following sections summarise our technical approach to delivering the project.

2.1.1. Desktop Research

Key Issue Identification and Characterisation

Energeia undertook a comprehensive review of international industry reports related to solar PV integration, and Australian content, including:

- AER Proposals and Determinations
- DNSP DAPRs and other reports
- Industry Pilots and Trials:
  - ARENA funded reports
  - Demand Management Innovation Allowance (DMIA) reports

We engaged with stakeholder and subject matter experts on the Steering Committee, as well as our own industry network, to identify key issues and potential sources of information.

With a short list of validated key issues in hand, Energeia applied the following analytical and research framework to identify and characterise the key issues arising from increasing DER penetration:

1. Investigated the drivers of each key issue to identify alternative drivers to solar PV and to relate DER penetration levels with impacts and associated costs by stakeholder; and
2. Assessed the current and projected future incidences of each issue to determine which are likely to be the most prevalent and costly across networks and how and why they may vary.

Key Solution Identification

After identifying DER export issues, Energeia then assessed the range of possible solutions with the following step process:

1. Developed a database of potential solutions as reported by DNSPs and others in AER proposals, DAPRs, DMIAs, Australian Renewable Energy Agency (ARENA) proposals and industry and academic literature;
2. Reviewed DNSP disclosures to understand the prevalence of these solutions;
3. Mapped the solutions that addressed each of the identified issues, noting other potential beneficial applications for the solutions, to inform potential cost allocation decisions; and
4. Investigated the cost and impact of each solution in terms of their effect on hosting capacity limitations, including the range of penetration over which the solution might operate effectively.

We also engaged with stakeholder and subject matter experts on the Steering Committee, as well as our own industry network, to validate our key solutions findings and conclusions.

2.1.2. Assessing Net Benefits

Energeia developed a high level, LV network DER integration model to estimate the cost of various potential solutions to identified issues over the target range of DER penetration. The model design was based on our experience modelling DER net benefits over the past 10 years, and our review of best practice approaches to modelling DER impacts and associated costs.

The modelling approach is detailed in Section 4 and will be implemented and reported on in the Stage 2 report, following consideration of feedback received on this Stage 1 report.

2.1.3. Documentation and Engagement

Energeia and Renew hosted a number of stakeholder engagement sessions throughout the project, which fed into the Stage 1 – Problem Statement paper (this report) and will also feed into the final, Stage 2 – Discussion and Options report (the final project report).

The Steering Committee includes representatives from distribution networks, retailers, consumer advocates and other parties, as shown in Table 3.

Table 3 – Steering Committee Composition

Segment	Name	Organisation
Network	Peter Wong	Jemena
	Justin Bethlehem	AusNet Services
	Brendon Hampton	SA Power Networks
	Therese Grace	Essential
Retailer	Travis Hughes	AGL
SME	Jonathon Dore	Solar Analytics
	Craig Chambers	Australian Renewable Energy Agency
	Robert Macmillan	Farrier Swier
Consumer Advocates	Rob Law	Central Victorian Greenhouse Alliance
	Gavin Dufty	St Vincent de Paul

Source: Renew

3. Stage 1 – Research Key Findings

Energeia's analytic framework shown in Table 4 used desktop research to identify the key issues arising from increasing DER in the LV network and the potential range of solutions that might address these issues. Energeia's findings from our research into the issues and solutions are detailed in the following sections.

Table 4 – Analytical Framework

Item	Staged Assessment	Key Questions
Issues arising from increasing DER exports	1. Identified issues	What are the issues observed from public domain sources (for networks, prosumers and other stakeholders)?
	2. Costs associated with the issues	How are stakeholders impacted by each issue and how? What are the associated costs with these impacts?
	3. Prevalence of the identified issues	Does the frequency of the issues vary across different distribution networks in the NEM? How does this compare internationally?
Solutions to address the identified issues	4. Identified potential solutions	What are the measures that distribution networks apply to manage the LV network?
	5. Prevalence of the potential solutions	What is the response to DER issues by DNSPs? How does this compare to overseas utility experiences?
	6. Solutions mapped to issues	Which of these solutions directly address DER issues?
	7. Key solution costs	What are the costs of these solutions to DER issues?

Source: Energeia; Note: DER = Distributed Energy Resources, DNSPs = Distribution Network Service Providers, LV = Low Voltage, NEM = National Electricity Market

3.1. Identified Issues

Energeia has identified a range of issues impacting across three distinct groups of stakeholders, the drivers and the impacts and costs, as outlined in Table 5.

Table 5 – Summary of Issues Associated with Rising DER Penetration

Stakeholder	Category	Issue	Impacts
Customers with Solar PV	Investment	Connection Limits	Connection standards can limit efficient investment choices in DER
		Export Limits	Connection standards can limit efficient operation of DER
		Inverter Curtailment	Inverter standards can reduce output and investment certainty
		Increased Energy Losses	Inverter standards can increase reactive power losses, reducing investment certainty
		Reduced Capacity	Inverter standards can increase reactive power, reducing inverter capacity and investment certainty
		Reduced Lifetime	Inverter standards can increase reactive power, reducing inverter lifetime, impacting investment certainty
Distribution Networks	Power Quality	Over-Voltage	Excess generation can increase voltage above allowed thresholds
		Under-Voltage	Generation can increase voltage range, leading to under-voltage
		Flicker	Intermittent generation can lead to voltage flicker
		Harmonics (THD)	Inverters can inject additional harmonics
	Reliability	Thermal Overload	Generation levels can exceed thermal rating limit
	Safety	Protection Maloperation	Changes in generation and load patterns can break some schemes
		Islanding	Inverters can fail to disconnect, creating safety issue
	System Security	Disturbance Ride-through	Inverters disconnect during disturbance, worsening the disturbance
		Under Frequency Shedding	Load shedding inverters can increase net load, worsening frequency
	Cost / Efficiency	Phase Imbalance	Inverters can be unevenly distributed, unbalancing the g rid
		Forecasting Error	Stochastic inverter uptake and output can reduce forecast accuracy
Generation, Transmission and Market Operations	Operability	Ramp Rate	Inverters can increase rate of change above system capabilities
	Reliability	Thermal Constraints	Large DER resources can overload thermal limits
	Safety	Fault Levels	Inverters can reduce fault current
	Cost / Efficiency	Forecasting Error	Uptake and operation can increase forecasting error
		Generation Curtailment	Curtailment of DER generation can increase wholesale market prices

Source: Energeia; Note: THD = Total Harmonic Distortion; Grey indicates that issue is addressed by current inverter standards.

Question 1. Do you agree that the above represents the key issues related to rising DER adoption based on total cost, including opportunity cost? If not, please identify your proposed changes and the supporting evidence for the changes.

3.2. Cost Associated with the Issues

Energeia identified the impacts and costs of the key issues associated with prosumers, distribution networks and other stakeholders, which are discussed in the following sections.

3.2.1. Customers with Solar PV

Table 6 details the key issues affecting customers with solar PV, namely limited connection limits, PV generation curtailment and increased energy losses.

Table 6 – Summary of Customers with Solar PV Issues

Category	Issue	Description	Impacts	Cost Type
Customers with Solar PV	Connection Limit	Connection limits size of system	Caps investment level	Reduced investment opportunity
	Export Limit	Limits amount of energy that can be injected at any time	Reduces investment level and revenues from generation	Reduced investment opportunity and/or certainty
	Curtailment	Over-voltage turns inverter off or DNSP export limits	Reduces revenues from generation	Reduced return on investment
	Increased Energy Losses	Higher reactive power increases inverter losses	Reduces bill savings and other benefits	Reduced return on investment
	Reduced Capacity	Higher reactive power reduces power capacity	Reduces peak demand payments	Reduced return on investment
	Reduced Lifetime	Higher reactive power reduces inverter lifetime	Shortens benefit stream	Reduced return on investment

Source: Energeia

Investment

Connection limits, generation curtailment, energy losses, power reductions and reduced lifetimes act to either restrict prosumer's investment opportunity or diminish the returns on an existing investment.

Connection Limit

All networks in the NEM have a connection limit restricting the size of inverters connecting to the grid to manage the PV export power flow through the LV network. Table 1 in Section 1.2.1 showed that most networks have a single-phase connection limit of 5 kW, with the exception of Ausgrid, TasNetworks, United Energy, Jemena and Western Power with a larger limit of 10 kW.[21]

The recent AEMC review of DER integration[22] has identified that the static limits are not a sustainable solution as they overly restrict customers' power generation potential and create inequities between early solar PV adopters and later solar PV adopters (whose connections are restricted).

Export Limit

Networks have recently begun to adjust their export limits to reflect the increasing number of single-phase solar PV systems connected to the grid, as well as the differences in costs for a three-phase system. For example, SA

[21] Customers can apply to install larger systems, with the outcome determined on a case-by-case basis by the DNSP.

[22] AEMC (2019), 'Economic Regulatory Framework Review: Integrating Distributed Energy Resources for the Grid of the Future': https://www.aemc.gov.au/sites/default/files/2019-09/Final%20report%20-%20ENERFR%202019%20-%20EPR0068.PDF

Power Networks' static export limit is proposing to reduce from 5 kW to 3 kW in areas of high solar penetration to allow new solar PV connections without unduly impacting other customers.[23]

Static export limits restrict a prosumers' ability to invest in larger DER systems and increase their revenue for DER exports (either from feed-in tariffs or through participation in Virtual Power Plants (VPP) or demand response activities). They may also unfairly favour customers with relatively high daytime loads.

Energy Networks Australia (ENA) is currently developing a unified national guideline[24] for DER export limits, which calls for a uniform "soft" export limit of 5 kVA for single-phase, and 5 kVA per phase with a balanced output for three-phase connections.

Generation Curtailment

The updated AS4777 (2015) inverter standard requires inverters to curtail exports in response to voltage exceedances[25] and grid outages[26]. Curtailment can also be driven by DNSP-specified export limits, as discussed above. Inverters can have several different curtailment mechanisms that work to reduce exports in the presence of high voltages, including:

- **Volt-Watt** – In this mode, the output power of the inverter is varied in response to changes in the terminal voltage. If this mode is available, AS4777 mandates that it shall be enabled by default.
- **Volt-Ampere Reactive (Volt-VAR)** – In Volt-VAR mode, the reactive power output of the inverter is varied in response to the voltage at its grid connection. Some inverters include an optional Volt-VAR response capability which is typically disabled by default.
- **Binary –** In this mode, the inverter will simply turn on or off.

The IEEE updated their standards in 2018 to include Volt-VAR response as a requirement. While Volt-VAR can lead to curtailment, we are seeking more information from stakeholders about the extent of it, and its impact on solar PV hosting capacity across different levels of solar PV penetration.

Curtailment affects prosumers through loss of benefits from solar generation. Curtailment frequency and the potential evolution of curtailment prevalence over time are unclear to consumers when they make their initial DER investment decision and are a significant source of dissatisfaction for prosumers with DNSPs.

Increased Inverter Energy Losses

When inverter power factor is not set to 1 it increases internal energy losses.

Setting inverter power factor can occur where connection standards require it, or as part of the Volt-VAR inverter standard. It is worth noting that the National Energy Rules (NER) mandate that a market network service must have a lagging power factor of 0.9[27], limiting maximum exported generation to 90% of rated power.

Higher inverter energy losses translate into higher electricity bills or lower feed-in tariff revenues for customers with solar PV, however, a key question is how significant these losses are, and what the net benefits of them are.

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[23] AEMC (2019), 'Economic Regulatory Framework Review: Integrating Distributed Energy Resources for the Grid of the Future': https://www.aemc.gov.au/sites/default/files/2019-09/Final%20report%20-%20ENERFR%202019%20-%20EPR0068.PDF

[24] ENA is currently running a process to develop national guidelines for DER grid connection. More details on the process, and the ongoing industry consultation is available here: https://www.energynetworks.com.au/assets/uploads/cmpj0127_technical_guideline_v6.0_basic_micro_eg_0.pdf

[25] AS4777 inverters limit grid exports during periods of high network voltages (over 253V). The voltage range limits, specified in the standard AS61000.3.100 Limits – Steady state voltage limits in public electricity systems, outline a nominal supply LV of 230V with limits of -6% to +10% (216V to 253V).

[26] The standard provides for compliant inverters to ensure the safety of distribution network technicians working on the network doing outage by preventing residential energisation during outages and provides mechanisms for residential solar to assist networks in managing network ramp up and ramp down periods either side of outages.

[27] AEMC, NER Chapter 5, S5.3.a, https://www.aemc.gov.au/sites/default/files/content//NER-v82-Chapter-05.PDF

Reduced Inverter Maximum Power

When inverter power factor is not set to 1 it reduces its maximum power output[28]. As is the case for increased inverter losses, non-unity (i.e. 1) power factor can be required by connection standards or Volt-VAR inverter standards. This is typically done by DNSPs to improve the efficiency of electricity transfer, reducing the need for augmentation of the distribution network at the cost of the solar PV applicants.

Although helpful to the network for voltage management, non-unity standards can negatively impact the local grid where solar PV output is helping to reduce peak demand, for example. It can also negatively impact solar PV customers by resulting in curtailment or "clipping" whenever panel power reaches the inverter maximum power.

Reduced Inverter Lifetime

Higher levels of reactive power produced by solar PV systems has been shown to reduce inverter lifetime. Studies commissioned by NREL[29] and Sandia National Laboratories[30] found that as the power factor of an inverter moves away from unity, it increases the temperature of the power semiconductors, resulting in a reducing useful lifetime. We invite stakeholders to share any relevant research or data on this issue.

A shortened inverter lifetime reduces a solar PV customer's return on investment.

3.2.2. Distribution Networks

Table 7 details the key issues reported by distribution networks across a range of categories ranging from technical (power quality, reliability, system security), safety and cost issues.

Table 7 – Summary of Distribution Network Issues associated with DER Exports

Category	Issue	Description	Impacts	Costs
Power Quality	Over-Voltage	Increased injection of real power increases line voltage above upper limit	Can cause inverters to shut down, damage appliances	Complaints, Investigations, Remediation
	Under-Voltage	Curtailment of injections reduces line voltage below lower limit	Can cause inverters to shut down, damage appliances	
	Flicker	Injection can vary widely and rapidly	Can increase voltage range, flicker	
	Harmonics (THD)	Inverters inject additional harmonics	Ran reduce transformer lifetimes	Remediation
Reliability	Thermal Overload	Injected power exceeds thermal rating	Can trigger over-current protection	Remediation
Safety	Protection Maloperation	Changes in current breaks some schemes	Can cause protection maloperation	
	Islanding	Inverter fails to disconnect	Can create a shock hazard	
System Security	Disturbance Ride-through	Inverters disconnect during disturbance	Can worsen frequency disturbance	Remediation
	Under Frequency Shedding	Load shedding inverters increases net load	Does not meet load shedding standard	
Cost / Efficiency	Phase Imbalance	Inverters grouped on single-phase	Can increase energy losses, reduces Tx capacity	Remediation
	Forecasting Error	Inverter uptake and output are stochastic	Increases forecasting error	

Source: Energeia; Notes: THD = Total Harmonic Distortion, Tx = Transmission, Grey indicates issue addressed by current inverter standards.

[28] GSES – Global Sustainable Energy Solutions (2015), '*Power Factor and Grid-Connected Photovoltaics*', https://www.gses.com.au/wp-content/uploads/2016/03/GSES_powerfactor-110316.pdf

[29] R. Thiagarajan et al., NREL (2019), '*Effect of Reactive Power on Photovoltaic Inverter Reliability and Lifetime*', https://www.nrel.gov/docs/fy19osti/73648.pdf

[30] Gonzalez et al. (2014), '*Effect of non-unity power factor operation in photovoltaic inverters employing grid support functions*', https://ieeexplore.ieee.org/document/6925199

Power Quality

Increases in DER penetration can impact distribution network power quality. These issues can impact both consumer devices and network operational efficiencies and include over and under-voltage, flicker, reverse flow and total harmonic distortion.

This is a salient issue for networks as they are required by regulation to provide the specified level of power quality to customers on their networks.

Over-Voltage

Over-voltage, defined as periods where the network voltage is higher than the allowed limit of 253 V, has been identified as the main issue currently facing networks in integrating residential solar uptake.

Over-voltage can cause inverters to shut down, and has the potential create excessive heat and strain on electrical components of appliances, reducing their lifetimes.

Key drivers of distribution network over-voltage include:

- **Network Management Practices** – Transformer tapping schemes can set the LV network voltage at too high of a level regardless of rooftop solar PV uptake. This can occur because of changes in loads and low to no LV power quality visibility.[31]
- **Grid Export from Solar PV** – Inverter real power injection into the network can increase voltage, particularly on high impedance circuits, e.g. overhead lines with relatively small conductor sizes.

DNSPs are required by their license conditions to keep voltage within Australian standards. With the nominal voltage recently being set to 230 V instead of 240 V, and the significant uptake of solar PV, many DNSPs are being required to re-tap their transformers to lower levels than their previous standard practices would dictate.

DNSPs deploy voltage monitoring equipment manually where needed in response to customer complaints. DNSPs with smart meters may be able to ping or read the customer meter to confirm the over-voltage situation.

Under-Voltage

The opposite of over-voltage, this condition occurs when the network voltage is lower than the allowed limit of 216 V. Although much less common than over-voltage, under-voltage can cause more significant consequences since in under-voltage conditions, appliances draw excessive current. Excessive current flows both increase the heat load of appliances and can trip network protection and outages. Hence, under-voltage induces costs for both the consumer, via appliance damage, and the network in outage-related costs.

Solar generation can sometimes contribute to under-voltage conditions arising in the LV network. Transient events, such as cloud cover, can cause a transient reduction in DER output resulting in a voltage drop. As distribution networks come to rely on more solar generation to meet their power needs, these effects will amplify. Current inverter settings can sometimes result in exaggerated voltage drop, as some inverters may switch off if they detect a voltage sag, exacerbating the original under-voltage condition.[32]

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[31] DNSPs rely on customer complaints to identify issues.

[32] Future inverter capabilities and settings (so-called "smart inverters") In the future smart inverters may have the opposite response and act to mitigate voltage sag. However, this technology is not currently implemented.

Flicker

Power-line flicker is the visible change in brightness of a lamp due to rapid fluctuations in the voltage of the power supply.[33] Voltage fluctuations resulting in light bulb flicker have been a common problem with LV networks since their inception, however this is changing as incandescent lighting technologies are phased out.

Recently, rooftop solar PV generation has been raised as a possible source of flicker due to voltage fluctuations generated by passing cloud cover and inverter disconnection. Although this is an intuitive possibility, Energeia has not been able to identify evidence of a causal link between unacceptable flicker levels and residential solar generation.

A recent study[34] has demonstrated the absence of correlation between cloud cover (irradiance) and flicker levels. On the other hand, a CSIRO study[35] of the ramp rate of PV installations in Australia found that high ramp rate events occur more frequently at smaller timescales, with observed power output reductions exceeding 66% of PV rating within a ten second period. This level of variation can impact flicker.

The cost of flicker is borne by consumers' who lose amenity and networks through the loss of customer satisfaction and consequential brand-name damage.

Total Harmonic Distortion

Total harmonic distortion (THD) is a measure of the cumulative amount of power generated by frequencies other than the fundamental 50 Hz frequency of the network. In a network, THD is typically caused by asynchronous generators and loads.

THD can increase network losses and reduce electrical equipment lifetime as energy is lost through heat, and devices that use inductive loads, such as electric motors, draw more power to operate correctly. Network transformers are also adversely affected by THD through increased losses and decreased life expectancy.

Solar panels generate DC power which is converted to AC power by the inverter when exported to the grid. Inverters use high frequency switching to generate an approximate sine wave, but the switching itself also generates higher frequency components. This distortion can be significant if many of the same type of inverter are connected to a specific area of the network. The amount of THD generated by grid connected inverters is restricted by Australian Standards. In their 2019 economic regulatory framework review[36], AEMC found no recorded incidences of solar PV installations generating significant harmonic distortion. On the other hand, AusNet have observed that harmonics induced by solar PV can trip bush fire safety controls.[37]

Other sources of harmonics include modern air-conditioners with variable speed drive inverters and other switch mode power supplies, which basically includes any DC device that connects to the grid with a 'wall brick', including mobile phones, computers, audio visual devices, etc.

Energeia has marked THD as no longer a material issue related to rising DER adoption in light of modern inverter standards and performance. Unless we hear otherwise from the consultation feedback, we will not include any solution costs for it in the options and net benefits maximisation analysis.

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[33] Flicker is a measure of human irritation, so it is difficult to measure and quantitatively quantify. It can cause adverse effects on human health including fatigue, lack of concentration, migraines and in extreme cases epileptic shocks. However, the subjective nature of the effect means that is difficult for either consumers or networks to attribute a cost to an effect that cannot be quantitatively measured.

[34] Spring et al., European Photovoltaic Solar Energy Conference (2013), *'Effects of Flicker in a Distribution Grid with high PV Penetration (2013)'*: https://pdfs.semanticscholar.org/9717/403435d7efb4b760984c0660ace41f51cde9.pdf

[35] CSIRO (2012), *'Solar intermittency: Australia's clean energy challenge'*: https://publications.csiro.au/rpr/download?pid=csiro:EP121914&dsid=DS1

[36] AEMC (2019), *'Economic Regulatory Framework Review: Integrating Distributed Energy Resources For The Grid Of The Future'*: https://www.aemc.gov.au/sites/default/files/2019-09/Final%20report%20-%20ENERFR%202019%20-%20EPR0068.PDF

[37] As was stated by an AusNet representative during the stakeholder workshop as part of the documentation process.

Reliability

Solar PV and other types of DER inverters can reduce network reliability by breaching asset thermal limits however, this only occurs during reverse power flow conditions.

Thermal Overload

Thermal overload occurs when current levels exceed rated limits causing excessive heat and resulting in accelerated asset aging, damage to network equipment and outages from tripped fuses.

Network voltage limits are usually reached well before thermal limits. However, as voltage remediations are implemented, it can lead to reverse power flow levels reaching thermal limits.

The cost of thermal overload impacts networks and consumers:

- Reduction in asset lifetimes leads to early asset replacement and thus network expenditure;
- Upgrades to assets to increase their thermal rating increases network expenditure; and
- Outages due to thermal overloads increase network expenditure and negatively impact customers.

Traditionally, thermal overload is caused by load. However, reverse power flow can also result in thermal overload due to reverse current.

Safety

Network safety can be impacted by DER via its effect on fault levels, protection mechanisms and islanding.

Protection Maloperation

Protection maloperation can occur due to rising DER penetration changing fault levels and/or reverse flows confusing protection mechanisms (i.e. the systems networks have in place to mitigate damage to their assets and potential loss of life). The addition of PV can also serve to desensitise the fault relay[38].

Maloperation of protection due to DER can therefore arise because the protection schemes were not designed with DER in mind. This can lead to false tripping of protection schemes due to higher than expected current flows, or reverse current flows, depending on the protection equipment.

Figure 14 illustrates how DER can alter the fault current needed for protection to operate effectively.

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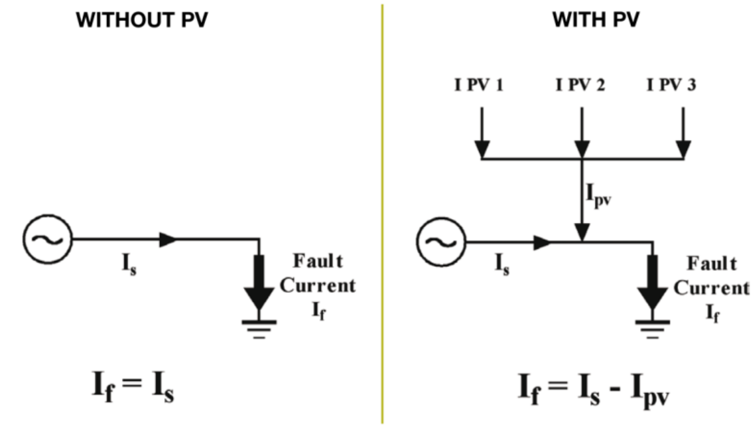
[38] NREL (2016), '*High-Penetration PV Integration Handbook for Distribution Engineers*', https://www.nrel.gov/docs/fy16osti/63114.pdf

Figure 14 – How High Penetration of Solar PV Systems may Reduce Fault Currents



Source: Endeavour Energy[39]

To resolve protection maloperation, the remediation will generally require networks to upgrade their protection systems to systems compatible with high levels of DER; e.g. installing a fuse with a higher interruption rating, and/or extra breakers closer to the PV load.

While protection maloperation can occur for a variety of reasons, the type of maloperations due to local changes in injection and load patterns are unique to DER.

Islanding

Islanding refers to DER systems supplying power to a grid when the grid power falls or fails, forming an island. The AS/NZS 4777.2 update in 2015 included requirements for inverter anti-islanding and disconnection functions to prevent islanding. Anti-islanding protection systems are designed to include N-1 redundancy[40].

Energeia has marked islanding as no longer a material issue for DER in light of the effect of the changes in the standard. Unless we hear otherwise from the consultation feedback, we will not include any solution costs for it in the options and net benefits maximisation analysis.

System Security

Increasing DER penetration can lead to changes in network security, including under-frequency load shedding.

Disturbance Ride-Through

Disturbance ride-through is the ability of inverters to remain operational during system disturbances including network faults to help keep the system secure. This issue is limited to grid-connected inverters.

Traditionally, grid-connected PV systems were designed to be disconnected from the grid under-voltage rise and drop conditions to protect the inverter. However, as DER penetration in the LV network increases, mass disconnection of a large amount of rooftop solar PV can disturb the stability of the network.

The AS/NZS 4777.2 update in 2015 included requirements for inverter disconnection functions to support disturbance ride through, and it is therefore not expected to be a major industry issue moving forward.

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[39] Endeavour (2011), *'Small Scale Domestic Rooftop Solar Photovoltaic Systems'*: https://www.elec.uow.edu.au/apqrc/content/technotes/UOW009_Tech%20Note%2010_AW_screen.pdf

[40] Ausgrid (2018), *'NS194 Secondary Systems Requirements for Embedded Generators':* https://www.ausgrid.com.au/-/media/Documents/Technical-Documentation/NS/NS194.pdf

Energeia has marked disturbance ride through as no longer a material issue for DER integration in light of the effect of the changes in the standard. Unless we hear otherwise from the consultation feedback, we will not include any solution costs for it in the options and net benefits maximisation analysis.

Under Frequency Load Shedding

Under frequency load shedding (UFLS) is implemented by DNSPs in cooperation with AEMO to restore power system frequency stability if system frequency drops below the operational set point during major disturbance.[41] It is an emergency response by the network to losing a large amount of generation, typically due to a power station or transmission line tripping off. UFLS arrests the system frequency drop which may otherwise lead to further grid separation and ultimately total frequency collapse and prolonged system outage.[42]

Increasing DER penetration has a two-fold impact on network's UFLS schemes:

- **Reduced System Inertia –** In LV networks where DER penetration is high, the increased level of DER exports reduces system inertia. If inertia drops low enough, frequency can drop faster than the UFLS scheme can operate.[43]
- **Generation Requirements** – Conventional emergency load shedding schemes implemented by distributors operate by disconnecting whole feeders at the substation. These schemes now need to consider the level of generation occurring at the time on the feeders, otherwise disconnecting the feeder to shed load could remove significant generation, further amplifying the under-supply issue.

UFLS settings are periodically changed to keep load shedding within the required standard.

The cost of UFLS failure is set by the Value of Customer Reliability (VCR) for a prolonged system outage.

Cost / Efficiency

Increase in DER penetration can lead to several issues around the cost and efficiency of distribution networks including phase imbalance and forecasting errors.

Phase Imbalance

Phase imbalance exists when one or more of the line-to-line voltages in a three-phase system are mismatched. Line-to-line voltages in a three-phase circuit typically vary by a few volts, but a difference that exceeds 1% can damage motors and equipment.[44]

Phase imbalance can arise in the LV network where customers on one phase adopt more solar PV generation than on another phase, causing the load to become unbalanced resulting in negative sequence voltage[45].

However, it can and does occur due to organic changes in load composition, for example, due to customers on one phase adopting more reverse cycle AC than on another phase. Phase balancing is a typical LV maintenance task as load patterns change over time.

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[41] Omar et al. (2010), *'Under frequency load shedding (UFLS): Principles and implementation'*: https://ieeexplore.ieee.org/document/5697619

[42] M. Lu et al. (2016), *'Under-Frequency Load Shedding (UFLS) Schemes – A Survey'*: https://pdfs.semanticscholar.org/1a02/af98d845f4e626665592b81c82551381ace8.pdf

[43] AEMO (2017), *'Power System Frequency Risk Review Report Non-Credible Loss of Multiple Generating Units in South Australia'*: https://www.aemo.com.au/-/media/Files/Stakeholder_Consultation/Consultations/Electricity_Consultations/2017/Power-System-Frequency-Risk-Report---Multiple-Generator-Trips---FINAL.pdf

[44] Enertiv (2019), '*What is Phase Imbalance?*', https://www.enertiv.com/resources/faq/what-isphase-imbalancec (Accessed 8/11/2019)

[45] AusNet (2017), '*Solar PV generator – Power Quality Compliance Requirements*', https://www.ausnetservices.com.au/-/media/Files/AusNet/New-Connections/Solar-Connections/Large-Solar/SOP-33-08---Power-Quality-Compliance-Requirements.ashx?la=en

Forecasting Error

Forecasting error in this context can be described as the difference between predicted and actual values of solar PV output and generation. As the prevalence of solar PV increases, networks must be able to accurately forecast their impact in the short and long-run in order to produce accurate forecasting methods.

The inability to accurately predict both the magnitude and spatial locality of DER could result in uninformed network planning leading to inefficient investment outcomes for customers, either through higher network costs, and/or increased power quality and reliability issues.

Other sources of forecasting error include any significant changes in load drivers, e.g. reverse cycle AC adoption, which led to significant increases in medium term forecasting errors in the NEM in the early 2000s.

3.2.3. Generation, Transmission and Market Operation

Energeia's research found that increases in DER penetration could potentially impact generation, transmission and operation of the market, as detailed in Table 8.

Table 8 – Summary of Generation, Transmission and Market Operation Issues associated with DER Exports

Category	Issue	Description	Impacts	Costs
Operability	Ramp Rate	Inverter rates of change are much higher	Increases ramping requirement	Remediation
Reliability	Thermal Constraints	Large DER resources overload thermal limits	Asset overloads and outages	Remediation
Safety	Fault Levels	Inverters reduce fault current	Transmission protection fails to operate	Remediation
Cost / Efficiency	Forecasting Error	Inverter output is stochastic	Increases forecasting error	Remediation
	Generation Curtailment	Curtailment of DER generation	Increased wholesale costs	Remediation

Source: Energeia

Operability

Increased DER can impact the operability of the system by increasing system ramp rate requirements.

Ramp Rate

Ramp rate refers to rate of change in system load or generation, which must be matched in real-time to maintain system stability. Historically, random and expected changes in load were matched in real-time by load following generation using automated governor controls (AGC).

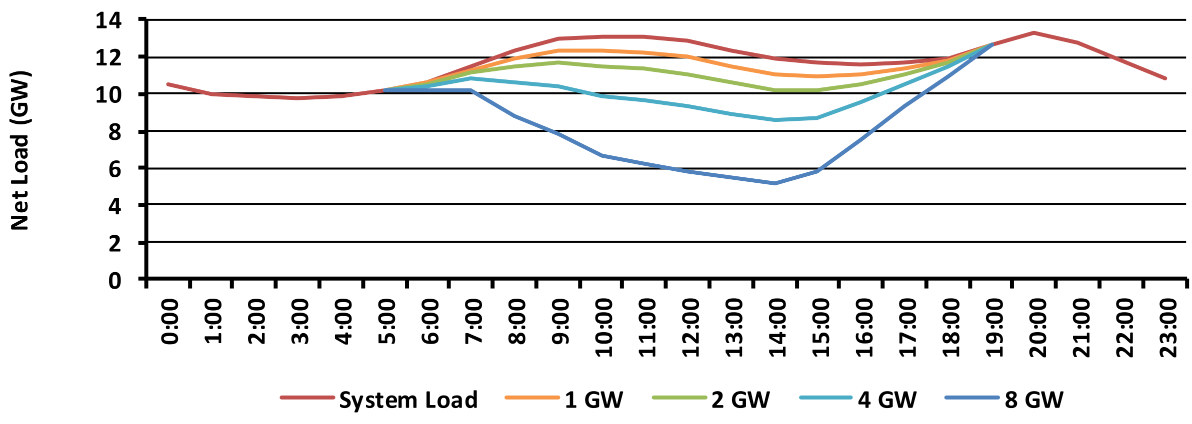
Changes in generator ancillary service (AS) requirements and associated changes in AS prices at least partially reflect the cost of increasing ramp-rate requirements.

High levels of DER penetration can increase the potential rate of change of the system, beyond the ability of conventional generation and load following systems. Solar PV only produces energy when the sun shines, however the demand for energy remains when solar energy is not being produced. The phenomenon is often referred to as the "duck curve", as shown in Figure 15. To ensure reliability under changing grid conditions, the system operator needs resources with ramping flexibility and the ability to start and stop multiple times per day[46].

Utility scale solar PV and wind resources can also drive changes in ramp rate requirements.

[46] CAISO (2016), "What the duck curve tells us about managing a green grid", https://www.caiso.com/Documents/FlexibleResourcesHelpRenewables_FastFacts.pdf

Figure 15 – Example Duck Curve by BTM Solar PV Capacity



Source: GreenTechMedia (2018)[47]

Reliability

Increased DER can impact the reliability of the transmission system by overloading transmission network assets.

Thermal Constraints

This issue is similar to the distribution network thermal limit issue but occurs at the transmission level.

This issue is generally not expected to occur anytime soon due to the significant level of DER required to overload a transmission asset – however it could potentially occur as penetration rises to expected levels.

Thermal limits have always been an issue, but new forms of generation, connected at different locations and voltage levels can cause flows on networks to change. This can lead to a change in the thermal constraints seen on transmission systems and a change in requirements for managing them.[48]

As is the case with the distribution network, load is the alternative driver of transmission thermal overloads.

Safety

Rising DER penetration can impact transmission system safety by reducing fault levels which can impact transmission level protection schemes.

Fault Levels

The displacement of rotating plant from the generation fleet in lieu of inverter based generation is leading to a reduction in fault levels at the transmission system level.

As such, protection devices installed may not recognise fault current and operate to protect transmission assets, creating a significant safety hazard as well as the potential to damage equipment.

While high levels of DER penetration can displace rotating plant, they are also displaced by utility scale solar PV, wind and storage resources.

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[47] GreenTechMedia (2018), "Massachusetts Is Staring Down a Duck Curve of Its Own. Storage Could Help", https://www.greentechmedia.com/articles/read/massachusetts-is-staring-down-a-duck-curve-of-its-own-storage-could-help

[48] National Grid (2016), '*Transmission Thermal Constraint Management*'': https://www.nationalgrideso.com/sites/eso/files/documents/National%20Grid%20Transmission%20Thermal%20Constraint%20Management%20information%20note_July%202018.pdf

Cost / Efficiency

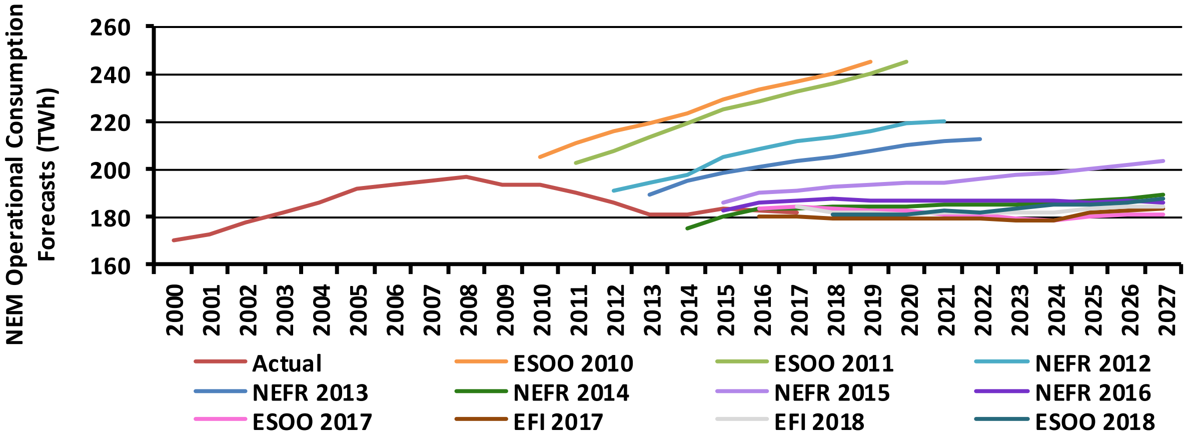
Cost and efficiency of the generation, transmission and market operation can be impacted through forecasting error and a lack of lower cost DER service due to curtailment.

Forecasting Error

Forecasting error in this context can be described as the difference between predicted and actual values of solar PV investment and output. Figure 16 provides the example of AEMO's forecasting errors.

Increased levels of rooftop solar PV can increase forecasting errors in the short and longer-term, which can in turn lead to sub-optimal levels of generation and transmission investment, as operating reserves. Sub-optimal investment and resource allocation increases market costs.

Figure 16 – AEMO's Long-term Forecasting Errors



Source: AEMO Electricity Statement of Opportunities (2018)[49]

PV generation is stochastic, and this can increase AEMO's short-term forecast error. For each five-minute dispatch interval, AEMO calculates the demand forecast error (DFE) for the period, that is, the percentage difference in the actual demand compared with forecast demand. AEMO has noted increases in the DFE in some regions at the times when solar generation is ramping up (increasing as the sun rises) and ramping down (decreasing as the sun sets)[50].

Large penetrations of DER, if not visible and predictable, could progressively decrease AEMO's ability to provide the level of accuracy needed to support market efficiency and/or reliability with asset under-utilisation, less informed investment decisions, and ultimately increased costs borne by consumers.

High levels of DER penetration can increase forecasting error, at least initially. However, intermittent, utility scale solar PV and wind resources can also drive increases in forecasting errors, due to the same stochastic factors.

Lack of Lower Cost DER Service due to Curtailment

Curtailment of lower cost DER resources can increase wholesale costs due to the dispatch of higher cost resources. This issue is increasing as additional utility scale solar PV installations are connected in the NEM. Figure 17 shows the non-synchronous generation curtailment in South Australia.

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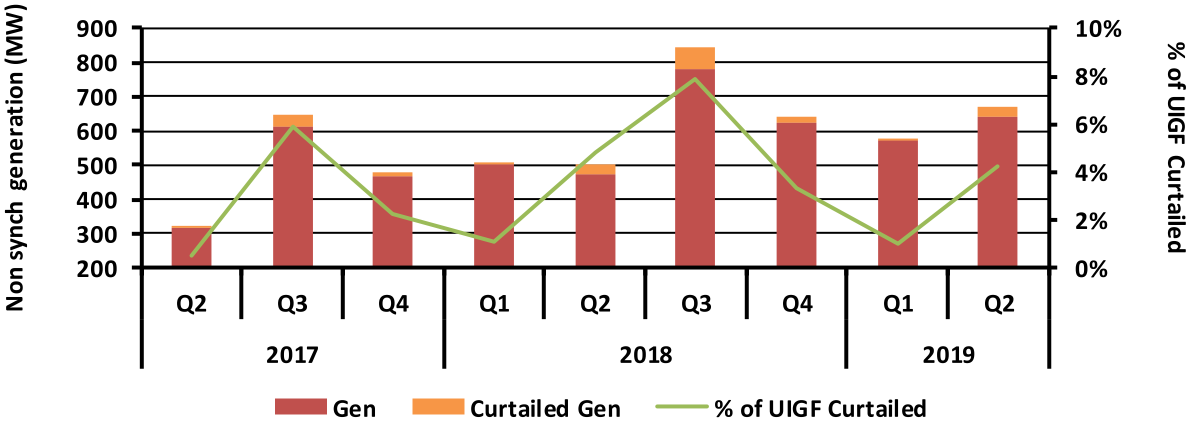
[49] AEMO (2018), *'2018 Electricity Statement of Opportunities':* https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/NEM_ESOO/2018/2018-Electricity-Statement-of-Opportunities.pdf

[50] AEMO (2017), *'Visibility of Distributed Energy Resources'*, https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Reports/2016/AEMO-FPSS-program----Visibility-of-DER.pdf

Figure 17 – Curtailment of Non-synchronous Generation



Source: AEMO[51]; Note: UGIF = Unconstraintеd Intermittent Generation Forecast

This issue varies slightly from the prosumer use case, in that the former involves the loss from the reduced bill and/or feed-in tariff payments, while this issue relates to the impact of DER on the wholesale market merit order, leading to a higher clearing price than would otherwise be the case.

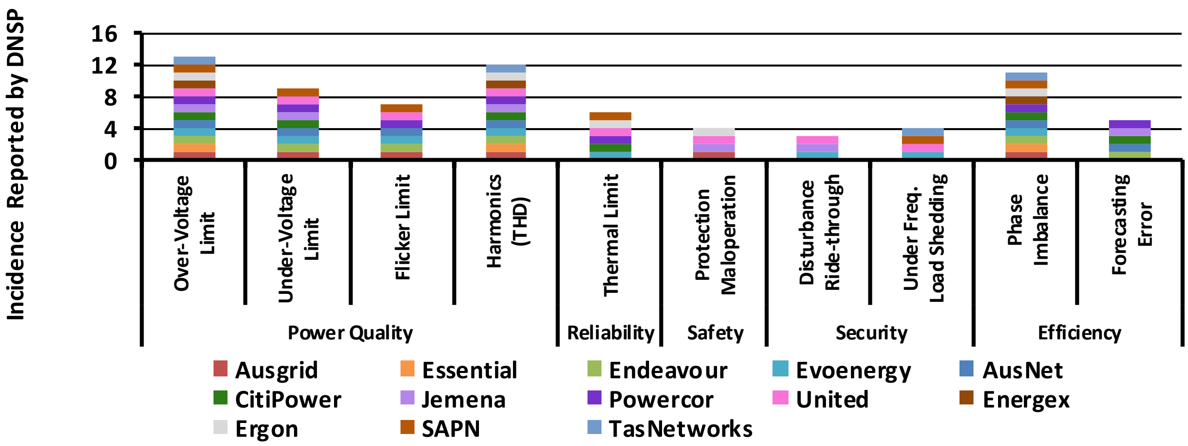
3.3. Prevalence of the Identified Issues

Energeia looked at the incidences of each issue to discover which are the most prevalent across networks and how they varied relative to international benchmarks, as shown in Figure 18 and Figure 19 respectively. Prosumer curtailment incidence was estimated in Section 1.2.2.

The most cited DNSP issues in Australia are over-voltage, harmonics and phase imbalance, with under-voltage and protection maloperation are in the next most frequent tier of reported issues.

Overseas jurisdictions, such as Germany, the UK, Norway and California report a similar range of issues, with an increased experience of under-voltage issues than Australia.

Figure 18 – Incidence of Key Distribution Network Issues Reported by DNSPs (Australia)



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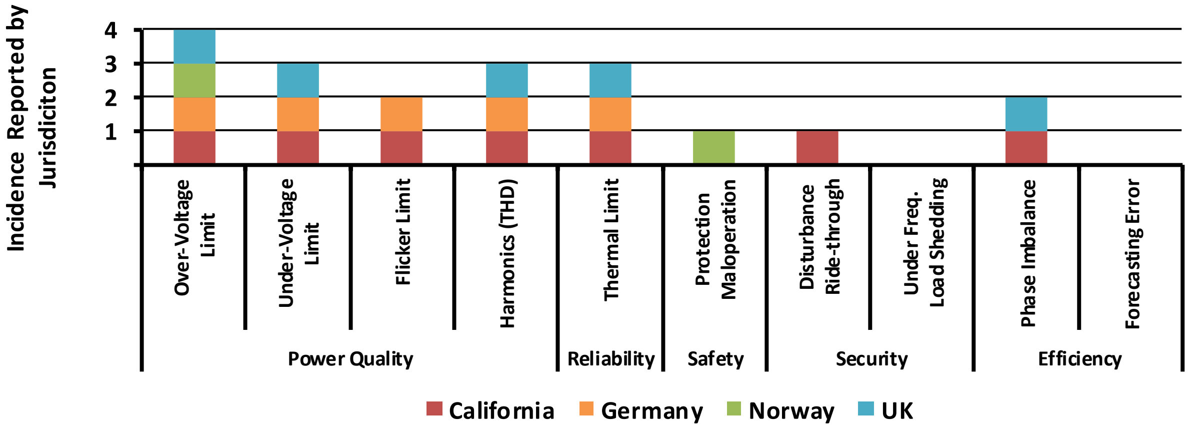
[51] AEMO (2018), *'Quarterly Energy Dynamics Q2 2018'*: https://www.aemo.com.au/-/media/Files/Media_Centre/2018/QED-Q2-2018.pdf (Accessed 8/11/2019)

AEMO (2019), *'Quarterly Energy Dynamics Q2 2019'*: https://www.aemo.com.au/-/media/Files/Media_Centre/2019/QED-Q2-2019.pdf (Accessed 8/11/2019)

Source: Energeia

Figure 19 – Incidence of Key Distribution Network Issues Reported by Overseas Benchmark Jurisdictions



Source: Energeia

3.4. Identified Solutions

Table 9 outlines the range of solutions that can be employed to remediate the range of key issues.

Table 9 – Key Options for Managing DER Export Issues

Category	Solution	Description
Consumers	Load Management	Shifting of water heating, pool pumping & under floor heating to soak up excess generation
	Storage Management	Use of storage to control Volt-VAR or to soak up excess generation
Pricing Signals	Coarse	Use of more cost-reflective pricing signals (e.g. tariff or rebates) that better reflect the value of marginal generation/consumption of real/reactive power, e.g. Time-of-Use
	Granular	Use of highly granular price signals that reflect the value of marginal generation/consumption of real/reactive power in real-time, e.g. Locational Marginal Price
Technical Standards	Inverter Standards	Changes to require DER inverter capabilities and settings at time of installation, including smart inverter capabilities, e.g. Volt-Var, Volt-Watt and Frequency-Watt
	Remote Inverter Configuration	Remotely configurable inverter capabilities, for managing voltage, frequency and other limitations by the network or service provider
	Static Limitations	Use of rating, rate-of-change or output limitations to ration available hosting capacity based on the worst-case scenario
	Dynamic Limitations	Dynamic setting of rating, rate-of-change or output limitations to make additional hosting capacity available as conditions warrant
Reconfiguration	Change Taps	Manual changes in transformer tap voltages to keep voltage profiles within limits
	Change Topology	Changes to MV and LV network topology to manage voltage and under-frequency load shedding issues
	Change UFLS	Changes to relay settings to maintain required load shedding and to avoid dropping circuits with reverse flow
	Change Protection	Changes to protection settings and schemes to resolve issues related to reverse flow
	Balance Phases	Manual changes in the allocation of single-phase connections to the three-phase system to maintain balance within standard
New Methods	Third Party Data	Customer side automation technologies that respond to market and network signal to improve efficiency and reliability of customer energy usage
	Better Forecasts	Improved analytical models to reduce or eliminate inverter related forecasting risk
New Assets	LV Metering	Installation of monitoring and control systems to monitor the LV network
	Voltage Regulators	Installation of transformer or line-drop voltage regulators to manage over or under-voltage conditions or to increase hosting capacity
	Larger Transformer and/or Conductor	Installation of larger transformers and/or conductors
	On Load Tap Changer	Installation of on load tap changers to enable real-time response to changing network conditions
	Harmonic Filters	Installation of harmonic filters
	STATCOMs	Installation of STATCOMs
	Network Storage	Installation of battery storage as a network asset

Source: Energeia

Each of the above solutions is discussed below in terms of the key issues it addresses, how it addresses them, any limits as to its application, who is using it, and key cost drivers.

3.4.1. Consumers

Consumers can use DER to shape their load profile and reduce their bill through:

- **Load Management** – Using behaviour change or controlled loads such as water heating and pool pumps to shift a portion of a customer's consumption to the solar peak hours, for example.
- **Storage Management** – Incentivising demand response or VPP programs to either control Volt-VAR or ensure that batteries are charging during the solar peak hours.

Load Management

By changing behaviour, installing time clocks, or modifying the designated controlled load tariff time period to the middle of the day instead of overnight, load management can be used to help reduce voltage rise and thermal limits. This solution is especially useful while consumer battery storage uptake is low. Water heaters, under floor heaters, pool pumps and electric vehicle charging are all examples of large, flexible residential loads, as shown in Figure 20.

Figure 20 – Example of Large, Flexible Customer Loads

Source: Energeia Research; Note: Shown are examples of a water heater, an electric vehicle charging and a pool pump.

Energeia identified a few examples of DNSPs in Australia using their load control systems to help reduce over-voltage issues[52], however, the practice does not yet appear to be widespread. Energeia has also been informed by industry contacts that some solar PV customers are taking their water heaters off controlled load and using time clocks to switch them on in the middle of day to use their excess solar PV generation.

The cost of implementing load management depends on whether existing solutions are in place, or new solutions have to be implemented. Retrofitting existing devices using a Demand Response Enabled Device (DRED) product is relatively expensive, while interfacing with an internet connected device will be relatively low cost.

Importantly, investments in load management to address DER driven issues could also be used for other network services, so it will be important to appropriately share costs where this solution is implemented.

Storage Management

BTM battery energy storage systems are typically used to store a customer's own excess solar PV generation as shown Figure 21. Research by the University of Melbourne shows that behind the meter storage could be used during solar PV curtailment periods to avoid curtailment.[53] A wide range of studies sponsored by ARENA have shown batteries can be used to remediate a range of issues including voltage rise and thermal overload.

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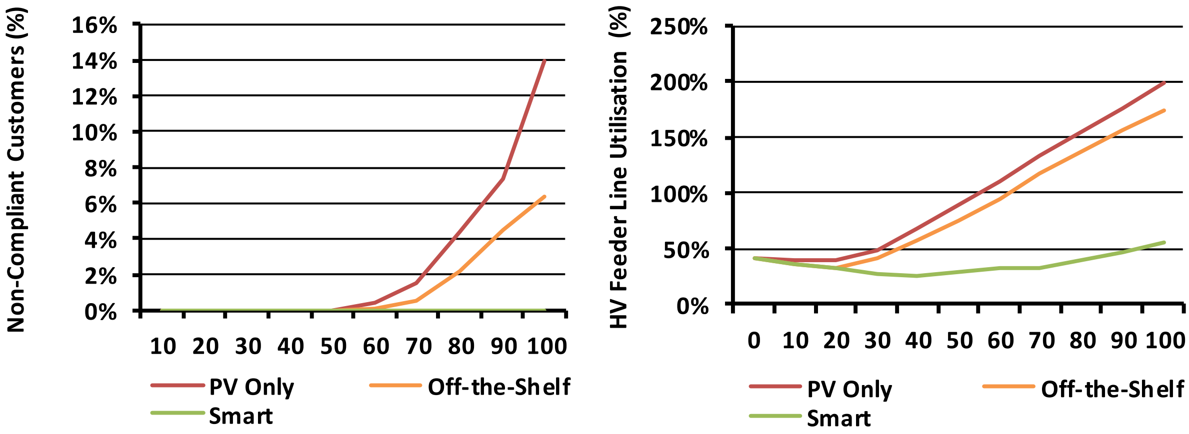
[52] Energex (2018), 'Distribution Annual Planning Report', https://www.energex.com.au/__data/assets/pdf_file/0016/720223/Distribution-Annual-Planning-Report-2018.pdf

Ergon (2018), 'Distribution Annual Planning Report', https://www.ergon.com.au/__data/assets/pdf_file/0018/720234/DAPR-2018-2023.pdf

[53] L. Ochoa, A. Procopiou, University of Melbourne (2019), *'Increasing PV Hosting Capacity: Smart Inverters and Storage'*: https://resourcecenter.ieee-pes.org/education/webinars/PESVIDWEBGPS0010.html pg. 14

Figure 21 – Using Storage to Eliminate Curtailment



Source: University of Melbourne[54]

VPPs in South Australia are reportedly using customer storage to address network issues including voltage rise.[55] Customers are receiving significant discounts or additional annual incentives to allow the VPP service provider to use their battery to provide network services.

Electric vehicle batteries could also be utilised as a solution provider in the, as vehicle-to-home and vehicle-to-grid technologies continue to develop.

As is the case for the load management solutions, the incremental cost of prosumer storage solutions will depend on whether the solution is already installed or not. If installed the cost will be at least the opportunity cost of using storage for other benefits, otherwise the cost will be the cost of a storage device and controls.

Again, investments in storage management to address DER driven issues could also be used for other network services, so it will be important to appropriately share costs where this solution is implemented.

3.4.2. Pricing Signals

As excess solar generation can cause power quality and reliability issues within the network, changing pricing signals to disincentivise DER output where it drives uneconomic costs is a potential solution to reduce the extent and frequency of these issues. There is a wide range of potential pricing and other incentive signals, the two categories below have been defined to provide pricing signal solution bookends:

- **Coarse** – Use of more cost-reflective pricing signals that better reflect the value of marginal generation or consumption of reactive power. These include tariffs, such as time-of-use tariffs, or rebates.
- **Granular** – Use of highly reflective price signals that track the value of marginal generation or consumption of reactive power. These include locational pricing or real-time pricing tariffs.

With these pricing signals, customers and/or their agents are incentivised to shift their energy usage including battery storage and EVs toward periods of excess solar PV output. Historically, take-up of optional cost-reflective tariffs has been poor. However, DNSPs have begun to mandate more cost-reflective pricing. For example,

[54] L. Ochoa, A. Procopiou, University of Melbourne (2019), *'Increasing PV Hosting Capacity: Smart Inverters and Storage'*: https://resourcecenter.ieee-pes.org/education/webinars/PESVIDWEBGPS0010.html

[55] Tesla (2019) '*RE: SA Power Networks: 2020 – 2025 Regulatory Proposal*': https://www.aer.gov.au/system/files/TESLA%20-%20Submission%20on%20SA%20Power%20Networks%20Regulatory%20Proposal%202020-25%20-%2016%20May%202019.pdf

Ausgrid is reassigning customers on flat tariffs to more cost reflective tariffs when they receive a new smart meter (including customers with DER) from 1 July 2019[56].

Importantly, price signals need not be mandatory, and voluntary, 'prices to devices' are more likely to be acceptable to customers and the regulator.

Locational pricing signals are typically used as part of the DAPR process, which estimates the avoidable cost of planned projects. They only relate to the proposed project, and not the long-term-marginal-cost (LRMC) of the location. No spatially determined LRMCs have been identified by Energeia's research.

Real-time, locational pricing is a feature of the NEM, at least on a regional (state) basis. The Coordination of Generation and Transmission Investment (COGATI) reforms will introduce nodal pricing at the transmission level, which provide real-time, location-based pricing. Energeia also identified Distribution System Operator (DSO) platforms that provide this information at the distribution network level; however, they are limited to pilot projects at this stage.

The cost of implementing more cost reflective pricing signals includes the cost of a smart meter if tariffs are used, however, other forms of price signals including rebates and device measured performance, could be close to zero to implement, other than the cost of the incentive itself. The cost of DSO platforms needed to determine nodal market clearing prices in real-time are high; but they are expected to fall as they become commoditised.

Investments in pricing signals to address solar PV driven issues could also be used for other network services, so it will be important to appropriately share costs where this solution is implemented.

3.4.3. Technical Standards

Research in the US[57] and Australia[58] show improvements to technical standards can significantly reduce curtailment and voltage rise issues. Energeia research has identified the following potential technical standards based solutions for remediating identified voltage, curtailment and frequency related issues:

- **Inverter Standards** – Changes to DER inverter capabilities and settings at the time of installation, particularly changes to Volt-VAR and Frequency-Watt standards.
- **Remote Inverter Configuration** – Capability for inverters to be remotely configured by networks or service providers, enabling dynamic reconfiguration and greater optimisation.
- **Static Limitations** – Changes to connection limits, rate of change or output limitations of grid exports.
- **Dynamic Limitations** – Dynamic setting of connection limits, rate of change or output limitations of grid export as conditions warrant

Importantly, any changes to standards will only be effective where there is effective enforcement of the standard.

Inverter Standards

The inverter standards outlined in AS/NZS 4777.1:2016 is available for implementation in Australia. The most recent updates to this standard improved PV installation practices and configurations, including the use of smart inverters to provide power system support functions and alleviate network power quality, reliability and safety issues (such as reactive control, over and under-voltage, fault ride-through and harmonic compensation).

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[56] Ausgrid (2019), 'Attachment 18 Tariff structure statement (2019 to 2024)', https://www.aer.gov.au/system/files/AER%20-%20Final%20decision%20-%20Ausgrid%20distribution%20determination%202019-24%20-%20Attachment%2018%20-%20Tariff%20structure%20statement%20-%20April%202019.pdf

[57] NREL, HECO (2019), *'Impacts of Voltage-Based Grid-Support Functions on Energy Production of PV Customers'*: https://www.nrel.gov/docs/fy20osti/72701.pdf

[58] L. Ochoa, A. Procopiou, University of Melbourne (2019), *'Increasing PV Hosting Capacity: Smart Inverters and Storage'*: https://resourcecenter.ieee-pes.org/education/webinars/PESVIDWEBGPS0010.html

The frequency-Watt inverter standard has been shown to be an effective method for managing under-frequency events in the Hawaiian network and may be a solution for managing the UFLS issue in Australian networks. Both Hawaii and California have implemented mandatory Volt-VAR and Volt-Watt standards, as shown below.

Table 10 – Summary of Key Inverter Standards from Selected Jurisdictions

Control Function Required	Australia	USA				Europe			
	General	General		Cali.	Hawaii	General	Italy	Austria	Germany
	AS/NZS 4777.2	IEEE 1547 Cat A	IEEE 1547 Cat B	CA 21	HI 14	CLC/TS 50549	CEI 0-16	TOR D4	BDEW MV
Volt-Watt	✓	✗	✓	✓ (optional)	✓ (optional)	✓ (optional)			
Volt-Var	✓	✓	✓	✓	✓	✓	✓	✓	✓
cos φ (P)	✓	✗	✗	✗	✗	✓	✓	✓	✓
Fixed cos φ	✓	✓	✓	✓	✓	✓	✓	✓	✓

Source: University of Melbourne[58]; Note: ✓ = Yes, ✗ = No, ✓ = Optional

Implementing new inverter standards will take time to address issues as older inverters fail or are replaced. It is also critical that new standards are enforced, or they won't have the expected impact.

The cost of implementing new standards includes the time and effort of agreeing them by industry stakeholders and implementing the new standards in devices. However, product development is a normal cost of doing business, and therefore not viewed as a significant incremental cost.

Remote Inverter Configuration

This standard would enable networks to remotely access smart inverters with internet connections and adjust their configuration to suit network conditions. Key settings that could be adjusted to manage power quality, reliability and network safety events include:

- Automatic disconnection of the inverter from the grid;
- Changing the power factor of the inverter;
- Limiting the ramp rate of the inverter; and/or
- Limiting the output of the inverter.

This added functionality would allow networks to effectively address location specific network issues. However, it brings with it a host of privacy and security challenges. Energeia research has identified this standard being implemented overseas in California[59] and Germany[60]; no Australian implementation examples were found.

Implementation cost of this solution will largely be driven by the back-office systems needed by DNSPs to manage device configuration management, which is not expected to be significant once off the shelf solutions are available. There will also be integration costs, but these are not expected to be material when completed as part of business as usual product development.

Static Connection Limitations

Static connection limitations are where distribution network limit the capacity of newly connected customer exports to ration available hosting capacity based on the worst-case scenario. In some instances, customers are not able to export any excess generation to the grid in regions of high DER penetration. In theory, if all additional

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[59] PGE (2018), 'EPIC Interim Report', https://www.pge.com/pge_global/common/pdfs/about-pge/environment/what-we-are-doing/electric-program-investment-charge/PGE-EPIC-Project-2.03a.pdf

[60] Bayer et al. (2018) 'The German experience with integrating photovoltaic systems into the low-voltage grids'; https://www.sciencedirect.com/science/article/pii/S0960148117311461

exporting capabilities were removed, all network issues (power quality, reliability, safety, system security and efficiency) solely caused by excess generation exported to the grid would not reoccur with new DER installations.

Although it may relieve the need to spend network expenditure to resolve additional network issues and improve hosting capacity for new DER installations, customers are no longer able to access feed-in tariffs or participate in demand response or VPP schemes and unlock the full suite of market benefits available for DER customers.

As mentioned in Section 1.2.1, most DNSPs are using this method currently, however, some are discussing reducing static limits in light of increasing voltage issues on their network.

Static connection limits are relatively inexpensive to implement, requiring mainly process changes, however, they increase the ‘hidden’ opportunity cost to prosumers of foregoing larger solar PV installations.

Dynamic Exports Limitations

Dynamic limitation setting involves applying limits to customer exports on a locational and/or time-varying basis reflecting network constraints. Under this approach, customers will not be limited in the capacity of their solar PV connection, but will be limited in their ability to export excess generation at certain times and at certain locations. This approach thereby addresses prosumer connection limitation and curtailment issues, and network voltage limit issues, and potentially other DNSP issues including UFLS, etc.

No Australian or overseas example has been identified of dynamic export limitation being implemented in practice, however, a number of Australian DNSPs are actively considering implementing it (i.e. via pilots like the Dynamic Limits DER Feasibility Study in NSW and South Australia[61]) and some, including SA Power Network, have included proposals in their latest AER submission.[62]

In contrast to static connection limitations, dynamic limitations are significantly more complex and costly to implement. Networks require greater visibility of network performance and DER on their LV network to identify regions and periods of constraint and the impact of applying a dynamic limitation framework before implementing dynamic limitations to customers. SA Power Networks assessed the cost of implementation in their 2019 LV Management Business Case report[62] as shown in Table 11.

Table 11 – SA Power Networks Cost Breakdown of Recommended Option

Work Package	2020-21 to 2024-25 Capex ($ ‘000)
LV Monitoring	$11,990
Build LV Hosting Capacity Model	$7,760
DER Database	$3,620
Dynamic Export Limit Calculation	$5,460
Transition and Program Management	$4,460
Total	$33,300

Source: SA Power Networks; Note: All costs are $2017 and include overhead costs.

3.4.4. Reconfiguration

Energeia research has identified a category of solutions that involve reconfiguring the existing network, assets, customer connections or secondary system settings to resolve network power quality, reliability, safety, system security and efficiency issues.

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[61] ARENA (2019), *‘Dynamic Limits DER Feasibility Study’*: https://arena.gov.au/projects/dynamic-limits-der-feasibility-study/ (Accessed 8/11/2019)

[62] SA Power Networks (2019), ‘LV Management Business Case: 2020-2025 Regulatory Proposal’, https://www.aer.gov.au/system/files/Attachment%205%20Part%207%20-%20Future%20Network.zip

The main solutions within this category include:

- **Manual Tap Changers –** Changing the transformer tap voltages to keep the voltage profiles within limits
- **Topology Changes** – Changing to the LV and/or MV network topology to manage voltage, protection and/or UFLS issues
- **Change UFLS** – Changes to relay settings and/or UFLS schemes to maintain required load shedding and to avoid dropping circuits with reverse flow
- **Protection Changes** – Changes to protection settings and schemes to resolve protection related issues
- **Phase Balancing –** Changes in the allocation of single-phase connections to the three-phase system to resolve phase imbalance issues

These potential solutions are detailed further in the following sections.

Changing Transformer Tap Settings

This solution involves reconfiguring tap changers installed on transformers to change the voltage profile, bringing it back into tolerance.

Changing tap settings is a very common solution to regulate voltage variations in the network. Offline taps typically operate over a limited band of voltage regulation, limiting their ability to effectively regulate wide or dynamic voltage profiles, which can be more common as DER penetration rises. Changing offline tap settings also requires an outage, which inconveniences customers.

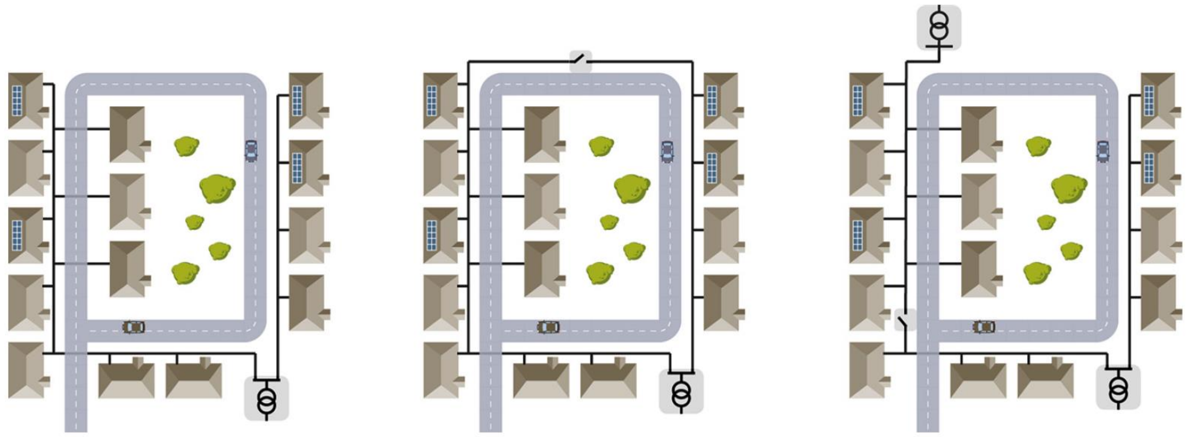
The cost of implementing changes to offline taps includes notifying customers of the outage, sending out the team to reconfigure the tap settings, and any impacts to the customer. Taps may need to be changed multiple times depending on how frequently the load profile changes.

Changing Network Topology

And HV LV network topologies can be changed to manage network power quality, UFLS and protection issues. Examples of network topology changes include modifying a section of the network from a radial grid, as shown on the left in Figure 22, to one of the following alternative topologies:

- **Ring grids** (as shown in the middle in Figure 22) – When closed, the ring grid can reduce grid resistance and therefore reduce voltage drops in the grid.
- **Second local distribution transformer** (as shown on the right in Figure 22) – Can alleviate reverse flow as a portion of the exported generation is transferred to the second local distribution transformer.

Figure 22 – Schematic of Radial Grid (left), Ring Grid (middle) and Second Local Dist. Transformer (right)



Source: Bayer et al. (2018) 'The German experience with integrating photovoltaic systems into the low-voltage grids'

Energeia research has identified overseas networks using topology changes as a solution, and there are anecdotal reports of using this approach in Australia as well. However, it is not likely to be that common as it represents a significant cost and effort. The key costs involved in this solution include the engineering time, customer outage notification (where needed), and field operator time to implement the new topology, and any additional assets.

Changing UFLS Settings

Changing UFLS settings involve reconfiguring the set of relays in the field used to shed load during an UFLS event in order to deliver the required level of load reduction.

As there are only a few networks such as Hawaii, South Australia and Queensland with a high enough penetration of solar PV to potentially require a change in UFLS settings, Energeia was unable to identify examples of UFLS schemes being reconfigured.

One issue with changing the UFLS settings is that they may have to be adjusted multiple times, similarly to phase rebalancing. As mentioned in Section 3.4.3, Hawaii is investigating the use of the Frequency-Watt inverter standard to provide UFLS-like compensation for under-frequency events.

The cost associated with changing UFLS settings include the engineering resources required to design the solution and the field crew resources required to implement it. It may be required multiple times, and it may not be possible to use the current UFLS approach under high levels of DER penetration.

The cost associated with changing UFLS settings include the engineering resources required to design the solution and the field crew resources required to implement it. It may be required multiple times, and it may not be possible to use the current UFLS approach under high levels of DER penetration.

As the UFLS system is periodically maintained by DNSPs in response to changes in load patterns, changes to accommodate additional solar PV installations may not be significantly incremental. However, there are limits to the level of solar PV capacity that can be accommodated by changes to the existing protection method.

Changing Protection Settings

Distribution network protection schemes operate to keep assets and people safe in the event of a fault. This is mainly achieved using a combination of relays and circuit breakers in MV networks, and fuses in LV networks.

Changing the protection scheme involves replacing relays or changing their operational settings, to cater for changes in the distribution of load, injections, and fault levels.

Analysis by the US Department of Energy's NREL found that rising solar PV penetration could drive protection maloperation, and called for reengineering the protection scheme to accommodate the change in conditions.[63] However, as reported in Section 3.6, Energeia has not identified any Australian networks reconfiguring their protection schemes at this stage, other than AusNet, due to THD issues.

As for the UFLS solution, the cost associated with changing protection settings include the engineering resources required to design the solution and the field crew resources required to implement it. It may be required multiple times, and it may not be possible to use the current protection approach under high levels of DER penetration.

As protection systems are periodically maintained by DNSPs in response to changes in load patterns and scheme performance during faults, changes to accommodate additional solar PV installations may not be significantly incremental. However, there are limits to the level of solar PV capacity that can be accommodated by changes to the existing protection method.

[63] SunShot, U.S. Department of Energy, NREL (2016) *'High-Penetration PV Integration Handbook for Distribution Engineers'*: https://www.nrel.gov/docs/fy16osti/63114.pdf, pg. 13

Phase Rebalancing

Phase balancing involves the reallocation of customers on single-phase connections to a three-phase connection to maintain balance within standard limits and releases capacity headroom and losses on feeders in the network.

A 2015 UK study[64] found that rural overhead feeders have the most potential for phase rebalancing as it is easier to visually determine and adjust the customer's phase connection compared to underground feeders. Even so, the study found it was cost-effective to rebalance the phases of customers on only a few feeders[65], suggesting that phase balancing is only an effective solution for specific regions of the network.

The costs associated with phase rebalancing are mainly related to the field crew resources required to rebalance the system. Phase rebalancing may be required multiple times, as differences between connections evolves with changes in solar PV, BTM storage and EVs adoption.

Phase rebalancing is a common LV network maintenance activity, and it will be important to ensure that any costs allocate to DER are demonstrably incremental to business as usual.

3.4.5. New Methods

Energeia's research identified new forecasting methods and third party data sources as two new methods being used to address emerging issues at lower cost than the traditional methods.

New Forecasting Methods

The impact of changes in DER adoption and major end uses on forecasting accuracy is described in Section 3.2.2.

This solution includes new forecasting methods such as machine learning, artificial intelligence and agent-based simulation, among others.

By improving forecasting techniques, networks can more accurately anticipate the adoption and operation of DER devices and use this information to more accurately estimate the expected impact on the network. With more accurate forecasts in hand, more efficient and prudent investment decisions can be made.

The costs of implementing new forecasting techniques are mainly related to changes in business processes and investments in new software and training. Costs for new forecasting systems can vary from under a million to over a million, depending on the software.

Improved forecasting methods adopted to address a DER driven issue could also provide additional benefits including more accurate load forecasts and/or improved unregulated business strategy, for example.

Third Party Data

This solution involves using third party provided data from smart meters inverters and other electronic devices to provide network monitoring services instead of investment in network monitoring and control systems.

Energeia's research has identified at least one DNSP that is actively looking at using smart meter and other third party data to inform their dynamic connection limit engine.

The cost of this solution depends on whether the devices are already installed, or need to be installed, with the later costs being much higher due to the need to visit and install the device, plus the cost of the device.

Once third-party data streams are in place, they could, depending on their frequency, latency, measurement unit and other key parameters, provide additional network services.

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[64] SP Energy Networks (2015) 'HV and LV Phase Imbalance Assessment', found here: https://www.spenergynetworks.co.uk/userfiles/file/HVandLVPhaseImbalanceAssessment16.pdf

[65] Was only cost effective for 9% of LV feeders monitored compared to other network planning options.

3.4.6. Adoption of New Assets

Networks can install a wide range of new assets as the solution to remediating network issues that may arise due to increasing DER penetration, including:

- **LV Monitors** – Installation monitoring devices to monitor the LV network
- **Voltage Regulators** – Installation of line-drop voltage regulators to manage voltage fluctuations and keep them within standard operating bounds
- **Larger Assets** – Installation of new transformers or conductors, mainly to relieve thermal overloads, voltage issues
- **On Load Tap Changer (OLTC)** – Installation of OLTC devices on transformers for dynamic voltage regulation
- **Harmonic Filters** – Shunting and blocking harmonic currents to improve network power quality
- **Static Compensators (STATCOMs)** – Installing STATCOM devices for dynamic voltage regulation
- **Network Storage** – Installing battery storage systems for voltage regulation and remediation of thermal overloads

Each of these are described in more detail in the sections below.

LV Monitors

LV monitoring involves installing monitoring equipment on the LV network to provide a stream of network performance data, including real and reactive power, THD and wave form capture, among other types of data.

Installing monitoring systems to monitor the LV network can be used to proactively identify and address voltage issues, inform and drive dynamic export limit schemes, and inform and drive voltage management schemes.

Various DNSPs have identified additional monitoring as part of their regulatory proposals. For example, SA Power Networks[66] has proposed the use of LV monitoring through smart meters to develop a LV hosting capacity model and facilitate dynamic export limitations. Implementing the monitoring process would cost the network approximately $12 million ($2017) over a five-year period. Additionally, Evoenergy[67] have proposed installing 200 power quality monitors each year, equivalent to $700,000 in network capex over a five-year period, to identify LV issues.

LV monitoring can also be used for a range of business as usual engineering applications, including improving reliability, and reducing capex and opex.

Voltage Regulators

Transformers or line-drop voltage regulators on distribution poles are a commonly implemented solution to LV network voltage excursions.

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[66] SA Power Networks (2019), 'LV Management Business Case: 2020-2025 Regulatory Proposal', https://www.aer.gov.au/system/files/Attachment%205%20Part%207%20-%20Future%20Network.zip

[67] Evoenergy (2018), *'Distribution Substation Monitoring and Supply Voltage Optimisation Program PJR'*: https://www.aer.gov.au/system/files/Evoenergy%20-%20Revised%20Proposal%20-%20Appendix%204.14%20-%20Distribution%20Substation%20monitoring%20PJR%20-%20November%202018.pdf

Figure 23 – Example of an Overhead Voltage Regulator

Source: Eaton

United[68] spent $579,000 between 2011 and 2015 on LV regulators, with an additional $2.6 million of forecasted expenditure to be spent over the 2016-2020 period. Voltage regulators can require replacing every 7-10 years, which further increases the lifetime capital cost of this solution.

Voltage regulators can be used to address DER driven voltage issues, but they are also widely used for business as usual voltage regulation as well.

Larger Assets

Traditionally, networks install larger assets, typically transformers or conductors, to remediate network issues, such as over-voltage or thermal overload, especially when continued growth was expected.

As reported in Section 3.6, most Australian and overseas DNSPs are using larger assets as a key solution to DNSP and prosumer issues arising from high penetration of DER.

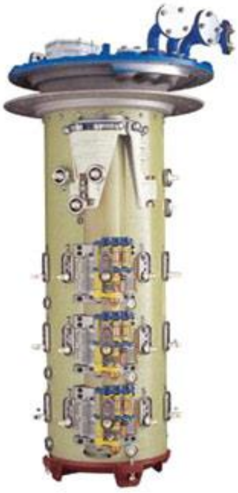
Larger assets can also provide additional services beyond those needed to address any issue arising from rising DER penetration.

On Load Tap Changer (OLTC)

OLTCs are a special type of transformer-based voltage regulators that can provide real-time response to changing network conditions. Changes in tap settings occur automatically and without the need for taking the transformer offline, unlike off load tap changers. An example of an OLTC solution is shown in the figure below.

[68] United (2015), *'Expenditure Justification – Power Quality Maintained'*: https://www.aer.gov.au/system/files/United%20Energy%20-%20RRP%205-9%20-%20Power%20Quality%20Maintained%20CEES%20-%20Jan%202016.pdf

Figure 24 – Example of an On Load Tap Changer



Source: Germes Online

OLTCs are traditionally used in special circumstances in MV networks, where the voltage profile is especially dynamic. Using them in the LV network is relatively new, and they are a relatively expensive additional cost. They also have a much shorter lifetime offline tap changers, and a higher maintenance cost.

Evoenergy's analysis[67] found that it was too expensive to deploy OLTCs to distribution transformers in the entire network, as opposed to those currently installed at the zone substation level. Additionally, a comparison of the costs of a voltage regulator and a OLTC by Eaton (2017)[69] is shown in Table 12, with an OLTC costing nearly twice as much as a voltage regulator over a 30-year period.

Table 12 – Comparison of Voltage Regulator Life Cycle Costs

	Regulator	Other Equipment	Initial Cost	Maintenance	30-year Cost
Voltage Regulator	\$95,000	\$2,500	\$97,500	\$10,000	\$147,500
OLTC	\$120,000	\$0	\$120,000	\$35,000	\$295,000

Source: Eaton (2017) 'Voltage Regulators vs. Load Tap Changers'; Note: Other equipment includes additional busywork and bypass switches, Maintenance costs are applied every five years, and thus would have five charges over the 30-year period.

As is the case with voltage regulators, OLTCs can be used to address DER driven voltage issues, but they are also widely used for business as usual voltage regulation as well.

Harmonic Filters

Harmonic filters are series or parallel resonant circuits designed to shunt or block harmonic currents, in other words, they provide a solution to THD related issues.

Other than AusNet, which is reporting solar PV inverters are driving increases in THD, Energeia's research has not identified this as a commonly implemented solution.

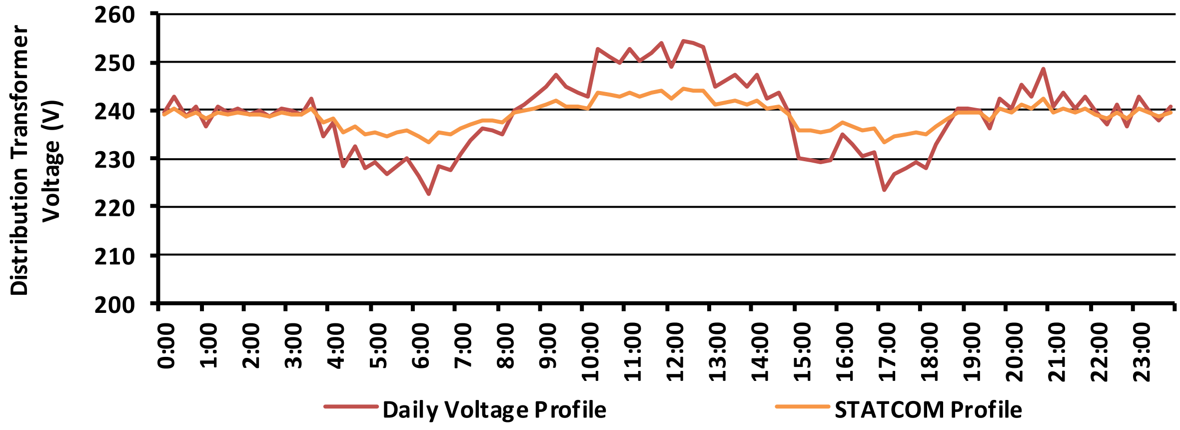
THD issues are relatively localised, and where they are needed, it is likely due to the behaviour of local devices on the network, which can include devices other than solar PV and other DER inverters.

[69] Eaton (2017) '*Voltage Regulators vs. Load Tap Changers*': https://www.eaton.com/content/dam/eaton/products/medium-voltage-power-distribution-control-systems/voltage-regulators/voltage-regulators-vs-load-tap-changers-information-td225012en.pdf

Static Compensators

STATCOMs are an additional form of voltage regulators used to provide more dynamic voltage control than OLTC, as shown in Figure 25. The dynamic functionality of STATCOMs provides a highly flexible solution, the effectiveness of which may be limited in regions of the network with high impedance.

Figure 25 – Static Compensator (STATCOM) Voltage regulation capabilities



Source: Ecojoule Energy[70]

Ausgrid's latest Regulatory Proposal[71] stated the intention of piloting the use of advanced voltage control technology, including STATCOMs, within the LV and HV regions of the network. Total indicative capital expenditure over FY20-24 is forecast to be $3 million. Endeavour has undertaken a trial with Australian company Ecojoule Energy where they will trial the EcoVAR LV STATCOM to help Endeavour manage the voltage on LV Networks. The project initiated earlier this year will install 20 EcoVAR units on power poles throughout their network in the Illawarra and Western Sydney region.

STATCOMs can be used to address highly dynamic DER driven voltage issues, but they can also be used to address dynamic voltage conditions driven by variable speed drivers and other types of loads.

Network Storage

Network battery storage systems are similar to the consumer-side solution; however, they are installed on network assets and/or in network right of ways. They are also owned and operated by DNSPs.

Ausgrid recently trialled[72] a small number of grid battery pilots to assess the viability of network use cases including the deferral of network augmentation through peak shaving, improving power quality and reliability outcomes, particularly in locations with high PV penetration, and provision of other network support services.

In addition to addressing issues that can be caused by DER, network batteries can be used to provide a wide range of traditional network services.

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[70] Ecojoule (2019), '*EcoVAR STATCOM*': https://ecojoule.com/wp-content/uploads/2019/06/EcoVAR_flyer-v3.pdf

[71] Ausgrid (2019) '*Revised Proposal, Justification for Operational Technology & Innovation Programs*': https://www.aer.gov.au/system/files/Ausgrid%20-%20Revised%20Proposal%20-%20Attachment%205.13.L%20-%20Justification%20for%20Operational%20Technology%20and%20Innovation%20Programs%20-%20%20January%202019.pdf

[72] Ausgrid (2019), '*Justification for Operational Technology & Innovation Programs*':https://www.aer.gov.au/system/files/Ausgrid%20-%20Revised%20Proposal%20-%20Attachment%205.13.L%20-%20Justification%20for%20Operational%20Technology%20and%20Innovation%20Programs%20-%20%20January%202019.pdf

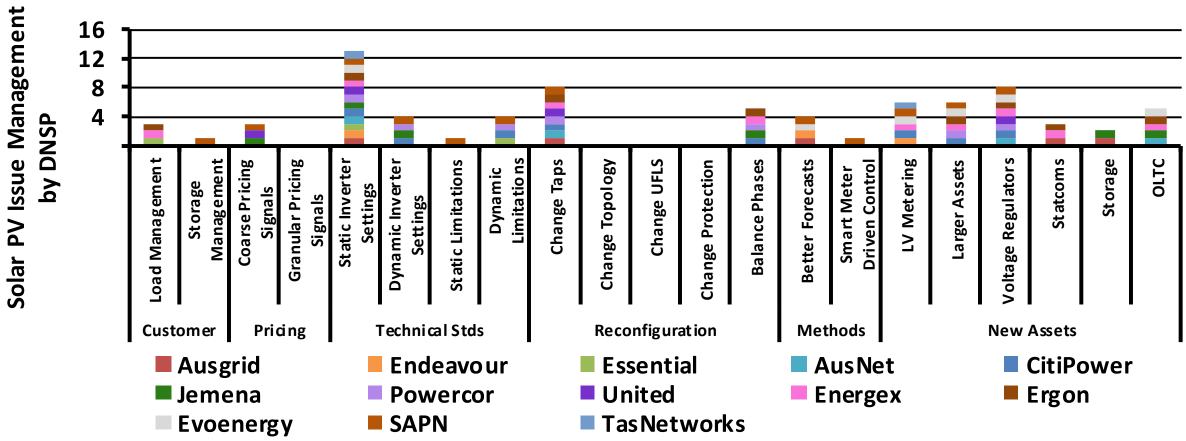
3.5. Prevalence of Solutions

Energeia's research identified the prevalence of the identified solutions across Australian networks and how they varied relative to international benchmarks, as shown in Figure 26 and Figure 27 respectively.

The most commonly cited solution in Australia is static inverter settings, with all networks implementing this in some form of a standard. The next most commonly cited solutions are voltage regulators and changing taps.

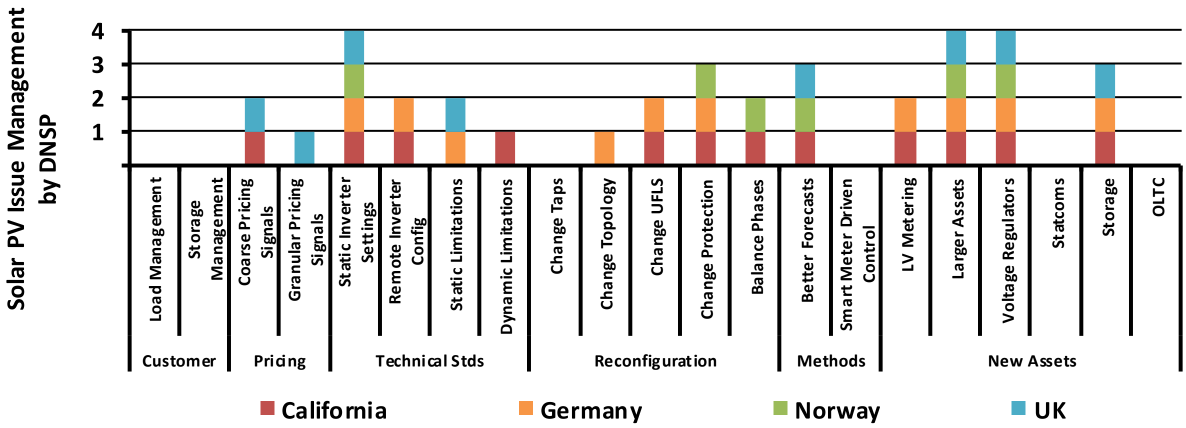
Overseas jurisdictions, such as Germany, the UK, Norway and California have similar prevalence of solutions, with an increased focus on installing new (larger) assets.

Figure 26 – Identified Solutions Incidence Reported by DNSP (Australia)



Source: Energeia

Figure 27 – Identified Solutions Incidence Reported by Overseas Benchmark Jurisdictions



Source: Energeia

3.6. Mapping Solutions to Issues

Each remediation has to potential to address a range of network issues. Energeia has mapped the identified solutions to the relevant DER export issues, as summarised in Table 13 and shown in detail in Table 14.

Table 13 – Summary Mapping of Remediation Options to DER Issues

Issue Stakeholder	Key Issue	Potential Solutions: Customers	Pricing Signals	Technical Standards	Re-configuration	New Methods	New Assets
Prosumer	Investment	✓	✓	✓*	✓*	✓*	✓*
Distribution Network Service Providers	Power Quality	✓	✓	✓*	✓*	✓*	✓*
	Reliability	✓	✓	✓*	✓*	✗	✓*
	Safety	✗	✗	✓*	✓*	✗	✓*
	System Security	✓*	✗	✓*	✓*	✓*	✓*
	Cost / Efficiency	✓	✓	✓*	✓*	✓*	✓*
Gen, Tx and Mkt Ops	Various	✓*	✓*	✓*	✓*	✓*	✓*

Source: Energeia; Note: Gen = Generation; Tx = Transmission; Mkt Ops = Market Operations;
✓ = Full Match (i.e. all of the potential solutions match all of the identified issues in these categories);
✓* = Partial Match (i.e. some potential solutions match some of the identified issues in these categories);
✗ = No Matches (i.e. none of the potential solutions match any of the identified issues).

Question 2. Do you agree that the summary above and detailed version below represents the key solution options to the key issues, and that the mapping of solutions to options is correct? If not, please identify your proposed changes and the supporting evidence for the changes.

Table 14 – Map of Remediation Options to DER Export Issues

Stakeholder	Category	Issue	Customers		Pricing Signals		Technical Standards				Reconfiguration					Methods		New Assets						
			Load	Storage	Coarse	Granular	Inverter Standards	Remote Inverter	Static Limits	Dynamic Limits	Change Taps	Change Topology	Change UFLS	Change Protection	Balance Phases	3rd Party Voltage	Improved Forecasts	LV Metering	Voltage Regulators	Voltage OLTC	Larger Assets	Harmonic Filters	STATCOMs	Network Storage
Prosumer	Investment	Connection Limits	✓	✓	✓	✓	✓	✓	✓	✓	✓					✓			✓	✓	✓		✓	✓
		Export Limits	✓	✓	✓	✓	✓	✓	✓	✓	✓					✓			✓	✓	✓		✓	✓
		Curtailment	✓	✓	✓	✓	✓	✓		✓	✓					✓			✓	✓	✓		✓	✓
		Losses / Lifetime	✓	✓	✓	✓	✓	✓		✓														
		Reduced Capacity	✓	✓	✓	✓	✓	✓		✓														
		Reduced Lifetime	✓	✓	✓	✓	✓	✓		✓														
Distribution Network	Power Quality	Over-Voltage Limit	✓	✓	✓	✓	✓	✓	✓	✓	✓					✓			✓	✓	✓		✓	✓
		Under-Voltage Limit	✓	✓	✓	✓	✓	✓	✓			✓				✓			✓	✓	✓		✓	✓
		Flicker Limit	✓	✓	✓	✓	✓	✓	✓							✓							✓	✓
		Harmonics (THD)							✓													✓		
	Reliability	Thermal Limit	✓	✓	✓	✓		✓	✓	✓											✓		✓	✓
	Safety	Protection Maloperation						✓	✓			✓		✓										
		Islanding						✓	✓			✓		✓										
	System Security	Disturbance Ride-through						✓	✓															
		Under Frequency LS	✓	✓				✓	✓				✓				✓	✓			✓			✓
	Cost / Efficiency	Phase Imbalance	✓	✓	✓	✓		✓	✓			✓	✓		✓								✓	✓
		Forecasting Error	✓	✓	✓	✓			✓								✓				✓		✓	✓
Gen, Tx and Mkt Ops	Gen	Ramp Rate							✓							✓	✓	✓			✓		✓	✓
	Reliability	Thermal Constraints	✓	✓	✓	✓		✓	✓	✓														
	Tx	Fault Levels						✓					✓											
	Mkt Ops	Forecasting Error	✓	✓	✓	✓		✓	✓	✓											✓		✓	✓
		Generation Curtailment	✓	✓	✓	✓		✓	✓	✓											✓		✓	✓

Source: Energeia; Definitions: THD = Total Harmonic Distortion; UFLS = Under Frequency Load Shedding; OLTC = On Load Tap Changer; Gen = Generation; Tx = Transmission; Mkt Ops = Market Operations;
Notes: Grey indicates obsolete issue with current inverter technology and standards

3.7. Key Solution Costs

Energeia used desktop research, consultation with the Steering Committee and our industry network to develop indicative cost estimates for each of the key solutions, broken down into capex and opex components as shown in Table 15[73]. These costs will be taken forward into the cost-benefit and optimisation analysis.

Table 15 – Key Solution Cost Estimates by Category

Category	Solution		Capex	Opex	Units
Consumer	Water Heater Management – Controlling Existing		$150	$15	kW
	Pool Pump Management - Controlling Existing		$50	$15	kW
	Storage Management - Controlling Existing		$50	$15	kW
Pricing	Coarse (e.g. ToU pricing), excl. smart meter		Negligible	$0	Customer
Signals	Granular (e.g. real-time pricing), excl. smart meter		$12m	$250k	DNSP
Technical Standards	Inverter Standards		Negligible	$0	DNSP
	Remote Inverter Configuration		Negligible	$0	Country
	Static Limitations		Negligible	$0	DSNP
	Dynamic Limitations		$6m	$250k	DNSP
Reconfiguration	Change Taps		Negligible	$1-2k	Trip
	Change Topology		$200k-$660k	$0	Feeder
	Change UFLS		$100k-$150k	$0	Feeder
	Change Protection		$1,000	$0	Feeder
	Balance Phases		Negligible	$1.5-$2k	Trip
New Methods	Third Party Data	New Install	$500	$5	Customer
		Previous Install	Negligible	$5	Customer
	Better Long – Term Forecasts		$8m	$250k	DSNP
New Assets	LV Metering		$3,500	$30	Transformer
	Voltage Regulators		$300,000	2.5% of capex	Regulator
	Larger Assets		$100k-$400k	2.5% of capex	Asset
	On Load Tap Changer	Vault	$120k	$7k	Transformer
		Pole-Mounted	$60k	$7k	Transformer
	Harmonic Filters		$500k	$0	Substation
	Statcom (Single-Phase)		$5-8k	2.5% of capex	LV Phase
	Network Storage		$550	2.5% of capex	kWh

Source: Energeia;
Notes: 1. Changes deemed to be part of existing operations excluded, e.g. introduction of new price structures. 2. In-depth consultation with DNSPs would be required on to better understand costs on a jurisdictional basis.

Question 3. Do you agree that the proposed solution costs are reasonably accurate? If not, please provide alternative cost estimates, and the evidence for their accuracy.

73 Energeia recognises that solution costs can vary widely according to numerous factors including network density and topography. These costs are intended to be estimates, and do not necessarily reflect the views of all Steering Committee members. More detail on the development of these costs is included in Appendix D.

4. Stage 2 – DER Integration Optimisation

In the Stage 2 paper, Energeia plans to implement the framework and approach proposed below to analyse and optimise the identified issues and proposed solutions across key LV network archetypes. Importantly, the framework is not intended to be used as a definitive framework or solution for any specific network. Rather, it is intended to identify the key issues and solutions and their indicative marginal costs.

Feedback is requested regarding the proposed modelling approach and key inputs.

4.1. DER Integration and Cost Modelling Approach

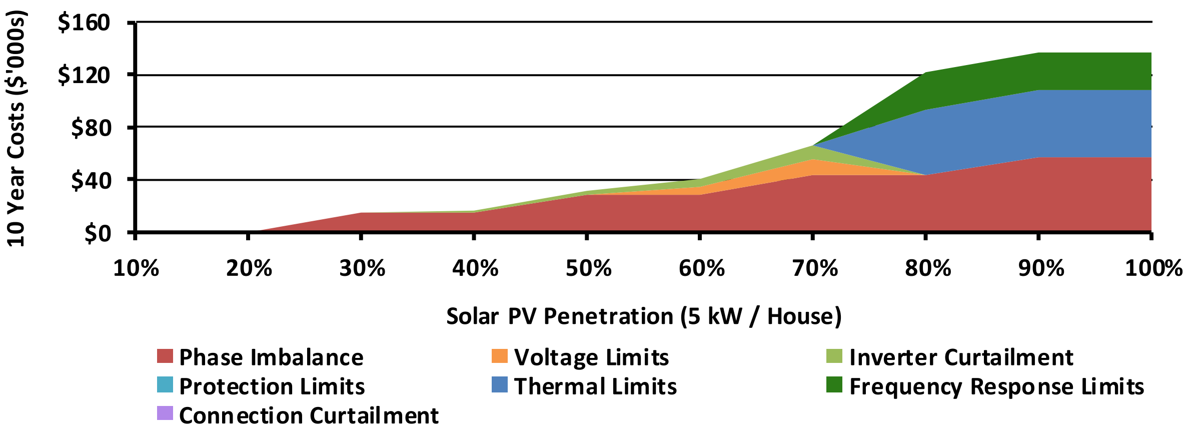
Energeia developed a high level, best practice DER-integration optimisation framework based on our research of best practice approaches to DER integration solution optimisation and our experience modelling the costs and benefits of DER across consumers, prosumers, DNSPs and the wholesale market.

The proposed solution optimisation approach models the costs and benefits of various solutions, for a given category or LV network, to identify the set of solutions that is expected to deliver the highest net benefits.

An illustration of the estimated cost of the current industry integration solution for a given LV network type (urban overhead, 200 kVA transformer) under a given scenario (moderate DER growth) is shown in the Figure 28. This example identifies the estimated costs across identified issue categories, by solar PV penetration level.

In the example below, at 20-40% PV penetration, only phase balancing is required, but as more PV generation is added, more issues arise and more solutions are required, such that at 70%, voltage limits and inverter curtailment are also required.

Figure 28 – Illustration of Network Integration Solution Costs by Inverter Penetration Level



Source: Energeia,
Note: Transparent colours (i.e. Inverter Curtailment) indicates cost of solution is borne by consumers rather than by DNSPs

To implement this approach, Energeia will need to develop a number of key assumptions for analysing the least cost approach to enabling 100% DER penetration, including the LV network topology, the existing hosting capacity and key constraint points, and impact of solutions in terms of increased hosting capacity.

Question 4. Do you agree that the proposed approach to modelling DER integration costs is reasonable for the intended purpose? If not, please identify an alternative approach and provide evidence for it being superior to the proposed approach.

4.2. Key LV Network Types

Energeia proposes to develop a high-level optimisation framework that we believe will provide useful insights into approaches with the highest net benefits, by applying a feeder typology approach. The benefit of this approach is that it can be scaled up quickly to identify the cost and benefit drivers and optimal settings of the same.

The framework can be applied to a wide range of key LV network segments, as outlined in Table 16.

Table 16 – Key LV Network Segments

Name	Customer Mix	Reliability Type	Construction
Res, Urban, Overhead	Res	Urban	Overhead
C&I, Urban, Overhead	C&I	Urban	Overhead
Res, Urban, Underground	Res	Urban	Underground
C&I, Urban, Underground	C&I	Urban	Underground
Res, Rural, Overhead	Res	Rural	Overhead
C&I, Rural, Overhead	C&I	Rural	Overhead

Source: Energeia Analysis; Note: C&I = Commercial and Industrial, Res = Residential.

Question 5. Do you agree with the key LV network types proposed are reasonable? If not, please provide alternative LV network categories, and the evidence supporting their use.

4.3. Key LV Network Characteristics

Table 17 provides an example of the key baseline characteristics Energeia plans to use for modelling each LV network type. Key characteristics that drive DER integration costs include whether the LV network is overhead or underground, its level of reliability, its current voltage and protection management schemes, its load mix, and the level of potential DER penetration.

Table 17 – Example of Key LV Network Type Assumptions

Assumption Type	Assumption	Notes
Transformer	11kV/415v	
Construction Type	Overhead	
Reliability Category	Urban	
Reliability Scheme	Normally Open Loop	
Protection Zones	1	Fuses so N/A
Transformer Rating (kVA)	50	
Off-line Taps	1	
Online Taps	0	
Line Voltage Regulators	2	
100% Res Customers	75	Assumes 50% headroom for switching
kWh/Res Customer	7,000	Defines PV MWhs per annum
100% PV kWs / Asset	5.0	
PV Capacity Factor	19%	

Source: Energeia

4.4. LV Solution Costs and Hosting Capacity Impacts

Energeia plans to take the indicative solution costs reported in Table 18 and develop estimates for each type of issue and each type LV network. Table 19 provides an example of how Energeia plans to apply the indicative cost data at the LV network level by issue category.

Table 18 – Key LV Solution Cost Assumptions

Cost Category	Units/LV	$/Unit	$/LV	Notes
PV VWA NEM* ($/MWh)	8,322	$100	$5,845,025	
Line Regulators	2.00	$50,000	$100,000	
Online Tap Change	0.50	$50,000	$25,000	
Phase Balancing	8.00	$7,200	$57,600	3 people for 8 hours at $100/hour 200% OH's
UFLS Reconfiguration	4.00	$7,200	$28,800	3 people for 8 hours at $100/hour 200% OH's

Source: Energeia, Notes: *: Volume Weighted Average price earned by BTM PV (i.e. FiT) in the NEM

Energeia plans on developing indicative estimates of each solution's hosting capacity impact, and the effective range of DER penetration that the solution can address (an illustrative example is provided in the table below).

Table 19 – Key LV Solution Timing Assumptions

Solar PV Penetration	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Inverter Curtailment	0%	0%	0%	0%	1%	1%	2%	4%	8%	16%
Phase Balancing	0%	0%	25%	25%	50%	50%	75%	75%	100%	100%
Voltage Limits	0%	0%	0%	0%	0%	25%	50%	75%	100%	100%
Frequency Response Limits	0%	0%	0%	0%	0%	0%	0%	100%	100%	100%

Source: Energeia

Energeia also plans on considering how these costs and impacts may evolve over time as part of the scenario design.

4.5. DER Integration Cost Driver Scenarios

The proposed solution optimisation approach is designed to model the costs and benefits of various solutions to identify the set of solutions that is expected to deliver the highest net benefits. Energeia proposes to use scenarios to address key risks, issues and uncertainties inherent in the modelling assumptions, such as:

- Future level of inverter-based generation on the system, e.g. solar PV, storage and V2G
- Future cost of solutions, e.g. storage, constraint engines, STATCOMS, etc.
- Future wholesale electricity costs, especially at times of solar PV generation
- Future level of prosumer participation in virtual power plants

An example scenario design framework is shown in the Table 20. Energeia will develop and agree scenario themes and driver settings with Renew prior to implementing them in the modelling.

Table 20 – Draft Scenario Design Framework

Driver Category	Scenario Drivers	Scenario Theme: Decentralised	Scenario Theme: Expected	Scenario Theme: Centralised
Technology Costs	Storage Costs	To be completed in Stage 2		
	Solar PV Costs			
	VPP Costs			
	LMP/DSO/etc. Costs			
Energy Costs	PV Weighted NEM Prices			
	Retail Electricity Prices			
Bulk System Costs	Ramping Prices			
	Flexible Prices			
Network Costs	LRMC			
	Tariff Reforms			
Customer Behaviour	Solar PV Adoption			
	Storage Adoption			
	EV Adoption			
	VPP/Peer-to-Peer Adoption			
	Gas Appliance Electrification			

Source: Energeia

Question 6. Do you agree that the DER integration cost drivers proposed for the scenario modelling are reasonable? If not, please provide alternative key cost drivers, and the evidence supporting their inclusion.

5. Next Steps

Please send your comments to Renew or Energeia at admin@energeia.com.au by the 15 February 2020 for consideration in our Stage 2 report, due out in early 2020.

ENERGEIA

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Appendix B – Updated Australian Standards

Standards on managing the LV network are outlined in the table below with key standards ensuring the following:

- **Power Quality** – Ensures steady state voltage limits at the customer connection point and limits the occurrence of voltage fluctuations or flickers.
- **Safety** – States the process and action required to maintain customer safety in over-current protection, faults and potential islanding of inverters.
- **System Security** – Outlines the frequency state that is required to maintain system security.
- **Reliability** – Provides a framework on the level of reliability to customers.

Low Voltage Management Standards

Category	Name	Standard	Requirements	Notes
Power Quality	Steady State Voltage	AS61000.3.100 Voltage Standard	Supply voltage range 230V +10%/-6% for 98% of the time	Published 2011, DNSPs should aim to deliver a lower average voltage, to allow for the connection of embedded generators
	Flicker	TR IEC 61000.3.7	Planning levels of Pst = 0.9 and Plt = 0.7	Recommended standard by ENA in 2014
	Transients	Not Found	-	Transient events fall within the steady-state voltage standards. However, Italy has a transient standard of <1 sec per MAIFI-transient event
Safety	Over-current Protection	AS/NZS 3000.2.5.2	Circuit breakers required in the event of overcurrent	-
	Fault Level	AS/NZS 3000.2.5.5	Protection shall be initiated at a current less than 30% of the three-phase prospective fault level	-
	Islanding	AS/NZ 4777.3-2005	Inverter must not connect to the grid if grid frequency is outside 45-55Hz or grid voltage is outside 200-270VAC single-phase or 350-470VAC three-phase	Values are subject to variation at the discretion of the local network operator
System Security	Under Frequency Load Shedding	Frequency Operating Standards	Load shedding schemes triggered when frequency is outside operational frequency tolerance band (49-51 Hz for NEM excl. TAS)	In 2019, it was decided following a review not to align the generation band to the operational frequency tolerance band
Reliability	SAIDI	Service Target Performance Incentive Scheme	Target SAIDI and SAIFI results lower than limit	Non-binding limits designed to encourage spending on reliability, vary by DNSP and feeder type
	SAIFI			

Source: Energeia; Note: ENA = Energy Networks Australia, DNSP = Distribution Network System Provider, NEM = National Electricity Market, SAID = System Average Interruption Duration Index, SAIFI = System Average Interruption Frequency Index.

Inverters provide the pathway for solar PV system to connect and export to the grid. There are several technical standards for inverters which provide a framework for network power quality, security and safety. The table below outlines the key components of the AS/NZS 4777 standards.

AS/NZS 4777 Technical Inverter Standards

Category	Name	Standard	Requirements	Notes
Power Quality	Voltage Rise	AS/NZS 4777.1:2016	AS/NZS 4777.1:2016 now specifies that the overall voltage rise from the point of supply to the inverter AC terminal to be 2% or less of the nominal voltage at the point of supply	Current standard was updated 2016, the previous standard was updated in 2005
	Power Factor	AS/NZS 4777.1:2016	0.95 leading to 0.95 lagging for inverters with rated nominal output currents up to 20 A per phase or; 0.90 leading to 0.90 lagging for inverters with rated nominal currents greater than 20 A per phase	-
	Inverter Power Quality Response Mode	AS/NZS 4777.1:2016	An inverter can maintain power quality at the point of connection through: Volt-Watt Response, Volt-VAR response, Fixed power factor or reactive power mode, or a power rate limit	-
System Security	Ride-Through	AS/NZS 4777.2:2015	DRM 3 Do not consume at more than 75% of rated power and source reactive power if capable	-
Safety	Anti-Islanding	AS/NZS 4777.2:2015	The automatic disconnection device must be able to inhibit the power from entering the point of supply or grid to avoid the formation of islanding with the grid	The most recent version of the standard (Previous version was updated in 2005) includes an anti-islanding in the event of DRM 0 - disconnect within 2 seconds of receiving signal from network
	Limits for Sustained Operation	AS/NZS 4777.1:2016	The inverter must disconnect from the grid within 3 seconds if the average voltage for a 10-minute period exceeds the nominal maximum voltage setting (default of 255V and maximum of 258V in Australia)	-

Source: Energeia

In addition to the AS/NZS 4777 standards, there are emerging international standards which focus on transitioning towards smart inverter capability to support the grid:

- **UL 1741 SA** – A product safety standard for inverters that outlines the manufacturing, software and product testing[74] requirements for smart, reactive control capability. A key focus is to transition from completely disconnecting, or anti-islanding measures, to adapting their output algorithm to assist in stabilising the grid.
- **IEEE 1541-2018** – An upgrade to the existing IEEE 1541 standard, the IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources with Associated Electric Power Systems Interfaces sets out requirements for grid supportive capabilities[75] from grid-connected DER technology, including inverters. The requirement also includes two way communication between the smart inverter and the grid which will allow for remote monitoring and control of the device

[74] Product tests include anti-islanding (with advanced features active during the test), low and high voltage ride through, low and high voltage frequency ride through, must trip test, ramp rate, specified power factor and vol/var mode. Optional tests include frequency watt and voltage watt. More information can be found here: https://legacy-uploads.ul.com/wp-content/uploads/sites/2/2016/08/UL-1741-SA-Advanced-Inverters.pdf

[75] Grid supportive capabilities from the IEEE 1541-2018 standard include voltage and frequency ride-through, voltage and frequency regulation and communication and control functionality.

Appendix C – Summary of DER Integration Initiatives

Energeia has characterised these responses in two broad categories, updates to standards and guidelines and industry initiatives. These are summarised in the following sections.

Updates to Standards and Guidelines

Both the Australian Standards process (for both network practices and technology), and the ENA National Connections Guidelines process have introduced updates to the Australian standards and guidelines:

- **AS Updates (Network and Inverter)** – Standards Australia continually update the Australian Standards for both operation and management of the LV network and the capabilities of inverters, and recent updates have responded to some of the known issues with both DNSP practice and inverter technologies.
- **ENA National Grid Connection Guidelines** – National Grid Connection Guidelines (released in September 2019) aims to provide standardised guidelines for the connection of DER across the NEM.[76] These guidelines provide a consistent technical framework for network service providers in Australia to adopt for small-scale DER and micro embedded generator connections at the LV, MV and HV level, consisting of connection process and technical requirements for connection. Although a voluntary industry framework, all Australian DNSPs have signalled their intention to adopt the guideline (which limits single-phase DER connections to 5kW and three-phase DER connections to 30kW).

Industry Initiatives

Various industry and government bodies (ENA, AEMO, ARENA, AEMC and others) are working collaboratively together to deliver a range of initiatives across grid connection, DER orchestration and DER integration.

These initiatives are currently in train or recently concluded and they include the following key programs of work by the following market and industry bodies:

- **ARENA** – Distributed Energy Integration Program (DEIP; currently in progress)[77], which aims to bring together the key stakeholders across the industry to influence the development of the regulatory environment for DER
- **ENA and AEMO** – Open Energy Networks Program (currently in progress)[78], which is focused on developing the market models for future distributed services operator (DSO) approaches to managing the LV network
- **AEMO** – Distributed Energy Resources Program (currently in progress)[79], co-ordinates AEMO's response to both the Open Energy Networks Program and ARENA's DEIP.

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[76] ENA (2019), *'Distributed Energy Resources Grid Connection Guidelines,* Technical Guidelines for Basic Micro EG Connections*'*: https://www.energynetworks.com.au/assets/uploads/cmpj0127_technical_guideline_v6.0_basic_micro_eg_0.pdf

[77] ARENA (2019), '*Distributed Energy Integration Program*': https://arena.gov.au/knowledge-innovation/distributed-energy-integration-program/ (Accessed on 8/11/2019)

[78] ENA (2019), '*Open Energy Networks*': https://www.energynetworks.com.au/projects/open-energy-networks/ (Accessed on 8/11/2019)

AEMO (2019), '*Markets and Framework*': (https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/DER-program/Markets-Framework (Accessed on 8/11/2019)

[79] AEMO (2019), '*Distributed Energy Resources Program*': https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/DER-program (Accessed on 8/11/2019)

- **AER** – Distribution Market Model project (completed in 2017)[80], lays out a vision for a competitive 'distribution market' which enables consumers to get the most value out of their DER market design changes; improved DNSP management of LV networks and guaranteed access for DER connections.

ARENA's Distributed Energy Integration Program

To maximise DER benefits to networks and consumers, ARENA has brought together a range of industry stakeholders (AEMO, Australian Energy Council, Clean Energy Council, Clean Energy Finance Corporation, Energy Consumers Australia, ENA, the Clean Energy Regulator, the Australian Energy Regulator, CSIRO and the AEMC) to prioritise and accelerate the reforms required to integrate DER into the existing market design.

The DEIP program involves the following:

- **Regulatory Reform** – How can the regulatory framework deliver an optimal amount of distribution network investment and non-network enabling expenditure, at the right time, to maximize net benefits to consumers?
- **Hosting Capacity Allocation and Investment** – How should distribution network capacity be allocated when there are competing users, and how should it be paid for?

AEMO and ENA's Open Energy Networks Program

ENA and AEMO launched the Open Energy Networks program investigating the most optimal pathways in DER integration into the grid. Their 2019 report[81] outlines the key DNSP capabilities required to support DER integration with minimal impact to customers and the grid, as shown below.

Open Energy Networks' Required Capabilities and Associated Milestones

Milestone 1	Milestone 2	Milestone 3
DNSPs defining network visibility requirements and network export constraints: • Define DNSP requirements for increased network visibility to maintain network operations within required parameters • Define how to achieve increased network visibility to maintain network operations within required parameters (operating envelopes) • Establish an iterative and targeted approach for the timing of investments required to provide network visibility to maintain network operations within required parameters	Defining communication requirements for operating envelopes: • Define protocols for operating envelope communication • Establish an Australian standards and/or guidelines to support the establishment of operating envelopes • Define data access permissions	Establishing an industry guideline for operating envelopes for export limits • Develop an Industry guideline that outlines the requirements and use of operating envelopes

Source: ENA and AEMO[82]

[80] AEMC (2019), '*Distribution Market Model*': https://www.aemc.gov.au/markets-reviews-advice/distribution-market-model (Accessed on 8/11/2019)

[81] Open Energy Networks (2019), *'Required Capabilities and Recommended Actions Report'*: https://www.energynetworks.com.au/sites/default/files/open_energy_networks_-_required_capabilities_and_recommended_actions_report_22_july_2019.pdf

[82] Open Energy Networks (2019), *'Required Capabilities and Recommended Actions Report'*: https://www.energynetworks.com.au/assets/uploads/open_energy_networks_-_required_capabilities_and_recommended_actions_report_22_july_2019.pdf

AEMO's DER Program

As the market operator, AEMO have identified the significant benefits that DER has on the electricity grid. As such, AEMO have released a 2019 report[83] discussing a pathway to better utilising DER for the grid through developing and improving appropriate DER standards. These would:

- Improve DER disturbance withstand capabilities, consistent with international practice.
- Expand use of beneficial grid support control modes (such as Volt-VAR, Volt-Watt, and Frequency-Watt), improving the hosting capacity of feeders and allow more consumers to install DER, without the additional network costs that would flow through to the continuum of consumers.
- Provide optimal support for system security.
- Enable consumers to utilise these capabilities to access new markets and services at a time of their choice.

AEMC's Distribution Market Model

As the market rule setting body, the AEMC completed a review of potential distribution markets in 2017. The AEMC laid out a vision for a competitive 'distribution market' which enables consumers to get the most value out of their rooftop solar panels, batteries and other distributed energy resources as we move to a lower emissions future. The report identified a range of enablers required to bring about this vision, namely:

- Increasing the opportunities for DER through market design changes;
- Improved management of network risks and opportunities, and;
- Developing a set of clear and consistent arrangements for DER connections.

[83] AEMO (2019) '*Technical Integration of Distributed Energy Resources, Improving DER capabilities to benefit consumers and the power system*': https://www.aemo.com.au/-/media/Files/Electricity/NEM/DER/2019/Technical-Integration/Technical-Integration-of-DER-Report.pdf

Appendix D – Detailed Solution Cost Breakdowns

Table 16 shows the initial Energeia cost breakdown of each solution, including descriptions and assumptions used. Table 17 shows the process of how DNSP feedback from the initial release helped to develop the final cost estimates.

Table 21 – Initial Energeia Key Distribution Network Solution Cost Assumptions

Category	Solution	Capex	Opex	Units	Description / Assumptions
Consumer	Water Heater	$150	$50	kW	Purchase and install time clock, or DRED device ($150/customer including installation)
	Pool Pump	$50	$50	kW	Reprogram pool schedule, or a DRED device ($50/customer including installation)
	Storage	$50	$50	kW	Change charging strategy to charge during peak PV output, per U. Melbourne study
Pricing Signals	Coarse	$0	$0	Customer	No incremental smart meter costs assumed
	Granular	$1M	$250k	DNSP	Implementation of next generation locational marginal pricing engine
Technical Standards	Inverter Standards	$0	$0	DNSP	No additional costs when included at design stage. Enforcement costs excluded
	Remote Inverter Config.	$0	$0	Country	Cost of communications port and security infrastructure, already included in most inverters
	Static Limitations	$0	$0	DSNP	Enforcement costs and lost opportunity costs excluded
	Dynamic Limitations	$1M	$250k	DNSP	Implementation of next generation operating envelope engine
Re-configuration	Change Taps	0	$1-2k	Trip	Manual tap change
	Change Topology	$200k-$660k	$0	Feeder	Per feeder
	Change UFLS	$2M	$0	Feeder	Estimated cost over determination period
	Change Protection	$1,098	$0	Feeder	Anti-islanding grid protection relay
	Balance Phases	$1.5-$2k	$0	Trip	Per one location
New Methods	Third Party Data	$1.5-$2k	$0	Customer	Per customer
	LT Forecasts	$500k	$250k	DSNP	Implementation of next generation forecasting software and processes, one per network
New Assets	LV Metering	$3,500	$30	Transformer	Evoenergy 200 monitors per year at $700K p.a., assumes uses existing LAN (opex of $6,000 a year)
	Voltage Regulators	$176,404	2.5% of capex	Regulator	$15.7 million ($2015) to install 89 bi-directional regulators into the network.
	Larger Assets	$100k-$400k	2.5% of capex	Asset	Per site
	OLTC	$120k	$7k	Transformer	Eaton $120k capex and a life cost of $295k (opex $35k every 5 years). UTS $200k-$300k
	Harmonic Filters	$518,693	$0	Substation	Per site; From a project which installed harmonic filters at five zone substations
	STATCOM	$5-8k	2.5% of capex	LV Phase	LV VAR compensators (STATCOMs) for single phase. Can stack 3 to build for three-phase
	Network Storage	$1.8-$2m	2.5% of capex	Asset	Grid battery project

Source: Energeia

Table 22 – Key Distribution Network Solution Cost Assumptions Estimation Process

Category	Solution		Energeia Assumptions		Revised Assumptions				Final Assumptions		
					DNSP 1		DNSP 2				
			Capex	Opex	Capex	Opex	Capex	Opex	Capex	Opex	Units
Consumer	Water Heater Management – Controlling Existing			$50				$15	$150	$15	kW
Consumer	Pool Pump Management - Controlling Existing			$50				$15	$50	$15	kW
Consumer	Storage Management - Controlling Existing			$50				$15	$50	$15	kW
Pricing Signals	Coarse (e.g. ToU pricing), excl. smart meter			$0	Negligible				Negligible	$0	Customer
Pricing Signals	Granular (e.g. real-time pricing), excl. smart meter			$250k			$11.99m*		$11.99m	$250k	DNSP
Technical Standards	Inverter Standards			$0	Negligible				Negligible	$0	DNSP
Technical Standards	Remote Inverter Configuration			$0	Negligible				Negligible	$0	Country
Technical Standards	Static Limitations			$0	Negligible				Negligible	$0	DSNP
Technical Standards	Dynamic Limitations			$250k			$5.46m*		$5.46m	$250k	DNSP
Re-configuration	Change Taps			$1-2k	Negligible	750			Negligible	$1-2k	Trip
Re-configuration	Change Topology			$0					$200k-$660k	$0	Feeder
Re-configuration	Change UFLS			$0			$100k-$150k		$100k-$150k	$0	Feeder
Re-configuration	Change Protection			$0					$1,098	$0	Feeder
Re-configuration	Balance Phases			$1.5-$2k	Negligible				Negligible	$1.5-$2k	Trip
New Methods	Third Party Data	New Install	$1.5-$2k	$0				$5	$1.5-$2k	$5	Customer
New Methods	Third Party Data	Previous Install	$0	$0	Negligible			$5	Negligible	$5	Customer
New Methods	Better Long – Term Forecasts			$250k			$7.76m*		$7.76m	$250k	DSNP
New Assets	LV Metering			$30					$3,500	$30	Transformer
New Assets	Voltage Regulators			2.5% of capex	$300,000				$300,000	2.5% of capex	Regulator
New Assets	Larger Assets			2.5% of capex					$100k-$400k	2.5% of capex	Asset
New Assets	On Load Tap Changer	Vault	$120k	$7k					$120k	$7k	Transformer
New Assets	On Load Tap Changer	Pole-Mounted					$60k		$60k	$7k	
New Assets	Harmonic Filters			$0					$518,693	$0	Substation
New Assets	Statcom (Single-Phase)			2.5% of capex					$5-8k	2.5% of capex	LV Phase
New Assets	Network Storage			2.5% of capex			Change to kWh		$550	2.5% of capex	kWh

Source: Energeia

Appendix E – Glossary

Table 23 – Glossary of Abbreviations/Acronyms

Abbreviation / Acronym	Meaning
ADMD	Average Daily Maximum Demand
AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
ARENA	Australian Renewable Energy Agency
AS	Ancillary Service
BTM	Behind-the-Meter
C&I	Commercial and Industrial
DAPR	Distribution Annual Planning Report
DER	Distributed Energy Resource
DFE	Demand Forecast Error
DMIA	Demand Management Innovation Allowance
DNSP	Distribution Network Service Provider
DRED	Demand Response Enabled Device
DSO	Distribution System Operator
ENA	Energy Networks Australia
EV	Electric Vehicle
FiT	Feed-in Tariff
HV	High Voltage
LMP	Locational Marginal Pricing
LRMC	Long-Run-Marginal Cost
LV	Low Voltage
MV	Medium Voltage
NEM	National Electricity Market
NER	National Energy Rules
OLTC	On Load Tap Changer
PV	Photovoltaic
Statcom	Static Synchronous Compensator
THD	Total Harmonic Distortion
UFLS	Under-frequency Load Shedding
V2G	Vehicle to Grid
VAR	Volt-ampere Reactive
VPP	Virtual Power Plant
VWA	Volume Weighted Average
ZS	Zone Substation

Source: Energeia

Energeia's mission is to empower our clients by providing the evidence-based advice using the best analytical tools and information available

Heritage

Energeia was founded in 2009 to pursue a gap foreseen in the professional services market for specialist information, skills and expertise that would be required for the industry's transformation over the coming years.

Since then the market has responded strongly to our unique philosophy and value proposition, geared towards those at the forefront and cutting edge of the energy sector.

Energeia has been working on landmark projects focused on emerging opportunities and solving complex issues transforming the industry to manage the overall impact.

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