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REPORT

LV Management Strategy

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Executive summary

Over the past few years SA Power Networks (SAPN) has observed significant changes in the types of equipment that customers have connected to the Low Voltage (LV) network. Instead of being passive, predictable devices, these customer devices (Distributed Energy Resources (DER)) are increasingly capable of exporting power to the network and of being managed by aggregators such that customers appear to act together.

SAPN has investigated the likely impact of these changes in customer behaviour through prior technical studies and also has evidence (through increased Quality of Supply enquiries) that demonstrates that the increasing uptake of customer DER is resulting in technical capacity of the LV network being exceeded. The requirements arising from increasing levels of DER are distinct from those of traditional load growth, particularly in relation to customer needs and the technical complexities of managing two-way power flows. The challenge facing SAPN was to find a solution that:

- Maximises value for all energy consumers, including DER and non-DER owners by ensuring that any investment is prudent, efficient and in the long-term interest of all customers.
- Enables customers to continue to install DER at forecast uptake rates while maintaining a safe, reliable and secure supply of electricity.
- Enables customers and the community to maximise the realisation of available value streams from their DER investment through participation in VPPs and access to markets for energy, ancillary services and network support.

SAPN engaged EA Technology to conduct a ‘hosting capacity study’ to identify the level of DER that could be accommodated by SAPN’s LV network. This study revealed that:

- The limits of the network are such that far less than the current export limits (5kW per customer) can be accommodated before issues are experienced;
- A reactive approach to LV management will therefore not be fit for purpose moving forward;
- Current initiatives and the use of tariffs to influence behaviour may increase hosting capacity, but are not sufficient to keep pace with forecast rates of DER uptake

Following this hosting capacity study, SAPN requested that EA Technology use its expertise to develop and investigate a range of potential strategies which SAPN could consider to respond to the challenge of increasing DER on the LV network. The DER management strategies considered were as follows:

- **Static limits (reducing existing static export limits):** allocating a static maximum export limit to each new DER owner (which in some cases may be zero export), avoiding extensive network augmentation.
- **Increase network hosting capacity (retaining the existing 5kW export limit):** where SAPN increases the hosting capacity on constrained circuits by upgrading network infrastructure or deploying a non-network solution, allowing customers to continue to connect DER while retaining the existing export limits.
- **Use of dynamic limits (reducing existing export limits dynamically, i.e. only when and where necessary):** modelling SAPN’s distribution network and DER operation to understand whether hosting capacity is likely to be exceeded and issuing dynamic export limits to the DER to keep the network within its physical limits, thus avoiding the need for extensive network augmentation. Two variants of this approach were modelled:
    - **Dynamic template approach**: based on extrapolation of representative network modelling (lower cost, lower resolution approach than building a full LV model);

- **Fully dynamic model**: based on using a full electrical model of the 75,500 LV networks (i.e. making use of higher resolution data, but at higher cost than the template approach).

The value of each of these strategies was assessed by investigating the cost to implement each strategy against the market benefits realised across SAPN's customer base by relieving constraints on DER exports. The value of relieving a constraint on DER export was based upon an independent valuation of avoided dispatch cost of alternative generation, in line with the approach taken in RIT-T assessments, to reflect the long-term value to all energy customers.

The outcomes of this analysis are summarised in Figure 1 below.

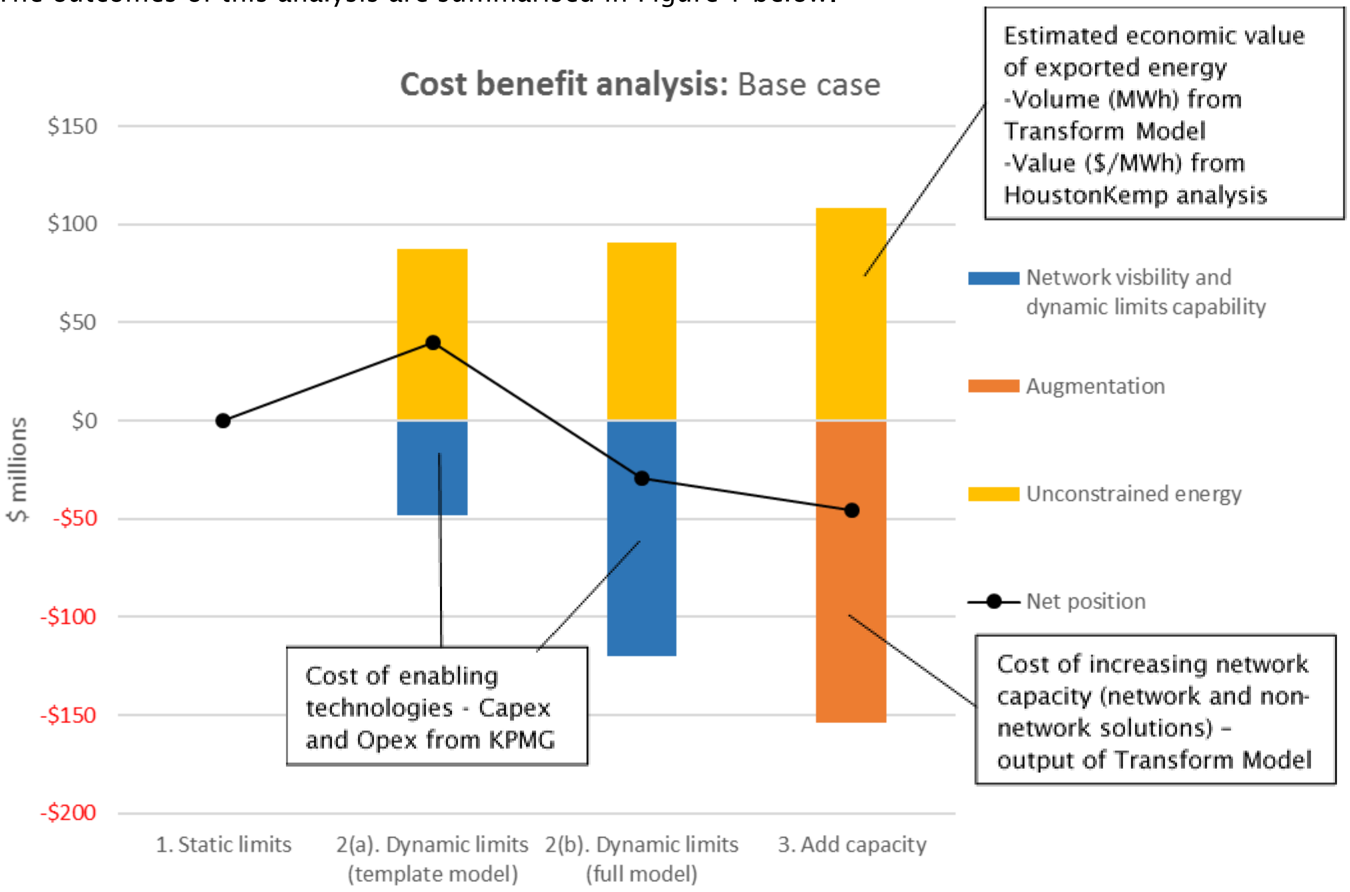

Figure 1 Cost-benefit performance of each strategy in base case conditions

This chart shows that when considered against a base option of imposing static limits on DER export, the strategy that generates the greatest level of benefit for customers is the Dynamic Limits (Template model) approach.

To ensure that the conclusions of this analysis were robust against an array of different DER growth scenarios, the cost benefit analysis was tested against seven different sensitivity cases, each with differing uptakes of PV, battery storage and electric vehicles; based on AEMO forecasts.

The results of the sensitivity analysis are illustrated by the cost-benefit chart in Figure 2. Each line shows the net position for one of the sensitivities considered across the three alternatives (dynamic templates, fully dynamic approach, and adding capacity through network augmentation) in comparison with the use of static limits when considered over the period 2020 – 2035.

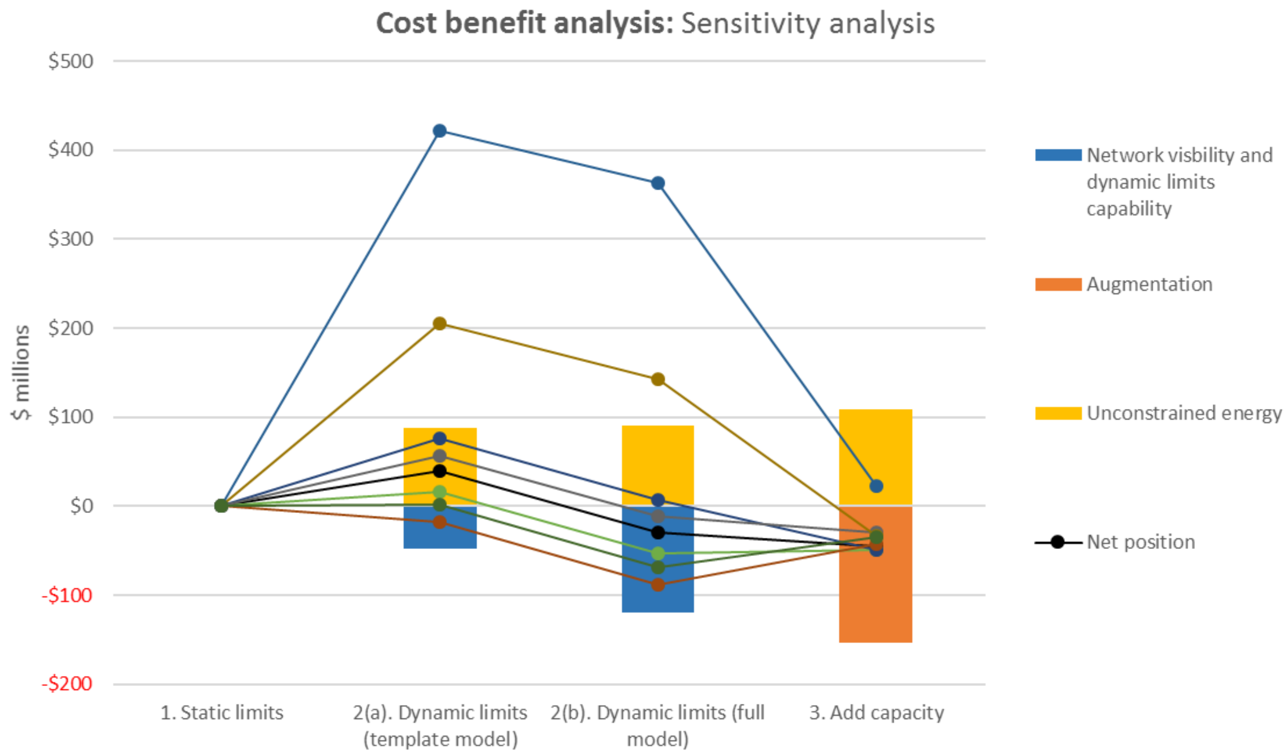

Figure 2 **Investment performance of each strategy relative to static limits.**

The analysis shows that in six out of the seven cases, the Dynamic Templates approach outperforms the static limits option. In all sensitivities, the Dynamic Templates strategy delivers a better outcome for customers than either the Fully Dynamic model implementation, or the approach of creating additional capacity through network augmentation.

This value is created because DER is allowed greater access to the network than offered by static limits, as constraints only exist for a small proportion of the year. However, to be able to offer this increased level of network access to customers, SAPN requires new capabilities to be able to decide when capacity is at risk of being exceeded and, moreover, the ability to manage DER to avoid this network capacity being exceeded.

This analysis found that the 'network augmentation' strategy was almost always the most expensive in comparison to deploying the static limits strategy. The 'fully dynamic' approach created more net value than the network augmentation approach, but because of the higher net cost did not outperform the 'dynamic templates' strategy.

Adopting a strategy which seeks to deliver the dynamic templates methodology is more likely to create the greatest net benefit for customers compared to other options considered. The Dynamic Templates approach provides the least risk to customers and the greatest level of potential savings and is therefore recommended as SAPN's LV Management Strategy.

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1. Background & Introduction

South Australia is at the forefront of the transition to renewable and distributed energy in Australia. Energy consumers are leading the charge by installing rooftop PV systems faster than anyone previously anticipated, approaching almost 1/3 of consumers. South Australia is also set to become the Virtual Power Point (VPP) capital of the world with several large VPP projects already announced or underway, including:

- AGL 1000 customer VPP
- Simply Energy 1000+ customer VPP
- Tesla staged VPP rollout, up to 50,000 sites
- South Australian government's battery subsidy of 40,000 residential storage systems which required subsidised systems to be "VPP ready".

These projects alone will provide opportunity for a significant proportion of the 850,000 electricity customers in South Australia to install energy storage systems and participate in VPPs.

To enable the transition towards distributed energy, SAPN needs to make a choice about how to integrate these systems with the distribution network in an economically efficient manner that maximises long-term value for all customers.

To investigate this, SAPN engaged EA Technology to perform hosting capacity analysis to determine the level of DER that could be accommodated on the network without the need for any intervention or change in current practice. The outputs of this analysis were used to assess the costs and benefits of various approaches to the future management of the LV network to ensure economically efficient integration of DER.

The challenge SAPN is facing is to choose a strategy to integrate DER that:

- Maximises value for all energy consumers, including DER and non-DER owners by ensuring that any investment is prudent, efficient and in the long-term interest of all customers.
- Enables customers to continue to install DER at forecast uptake rates while maintaining a safe, reliable and secure supply of electricity.
- Enables customers and the community to maximise the realisation of available value streams from their DER investment through participation in VPPs and access to markets for energy, ancillary services and network support.

This strategy seeks to determine the optimal investment option that meets these objectives.

2. Case for change

2.1 Distributed Energy Resources and future growth

The growth in customer adoption of 'behind-the-meter' distributed energy resources (DER) has accelerated at a rate that few had previously predicted with penetration levels in excess of 20% and in many network areas around 30%. Figure 3 shows the strong historical uptake which continues to exceed previous forecasts.

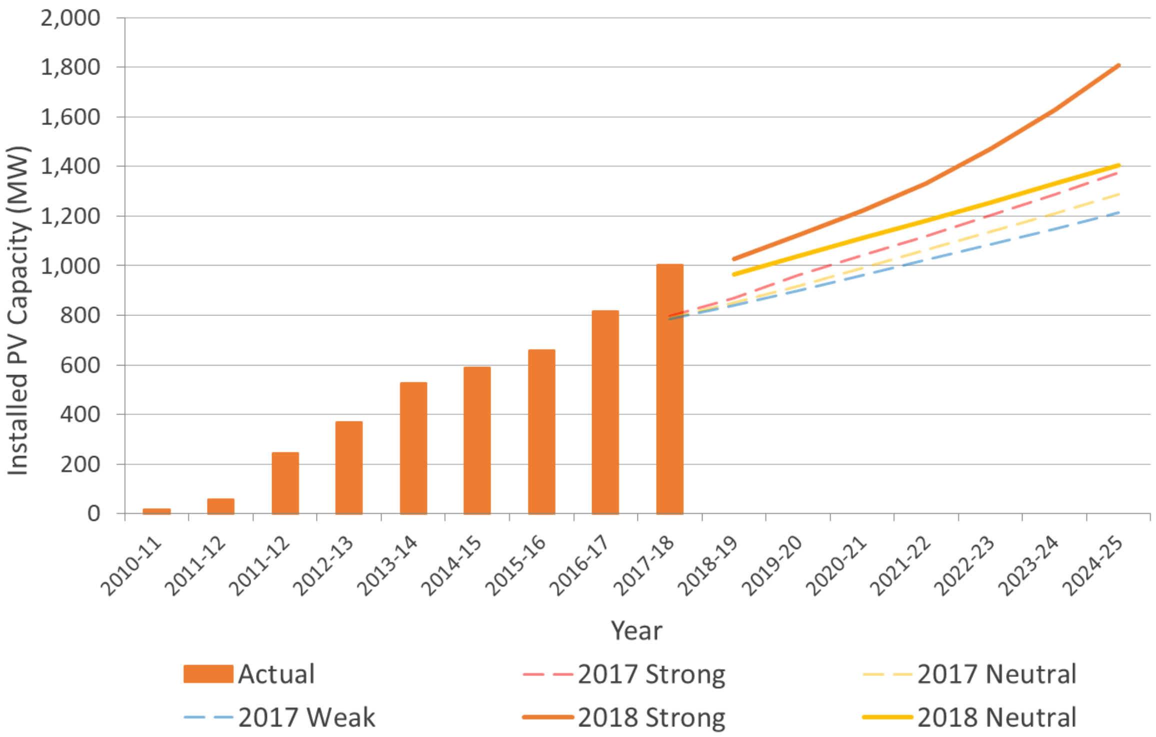


Figure 3 South Australia rooftop solar PV capacity to date, and AEMO forecasts

The widespread connection of small-scale generation and storage means that understanding and managing the once predictable technical aspects of the LV network becomes more challenging. The measure of the network's capability to accommodate the connection of solar PV and battery systems is known as the 'hosting capacity'. The hosting capacity is limited by two things:

- Voltage constraints

  SA Power Networks has a regulated obligation to maintain supply at the customer connection point between 216V and 253V, the range specified in Australian Standard AS60038. Solar and battery inverters must raise local voltage in order to feed energy 'upstream' back into the grid. Once rooftop PV penetration exceeds around 25%-30% of households in a local area, voltage at the customer premises can, at certain times, exceed the range specified in AS60038. This causes customer inverters to trip off, causes quality of supply issues to other customers on the local network and can cause damage to customer equipment.

- Thermal constraints

  As PV penetration grows in a local area, reverse current in the middle of the day can become greater than the traditional peak summer evening load that the network is designed for. When reverse current exceeds the thermal rating of an asset like an LV transformer or cable, these assets are subjected to increased stress which reduces their life and increases their risk of failure, resulting in supply outages for customers.

Figure 4 shows aggregated data from 100 customers who participated in SAPN's Salisbury battery trial and illustrates the significant change from the traditional daily peak demand of 150kW in the evenings to a new peak of 200kW reverse power flow generated by the undiversified output of the solar PV systems.

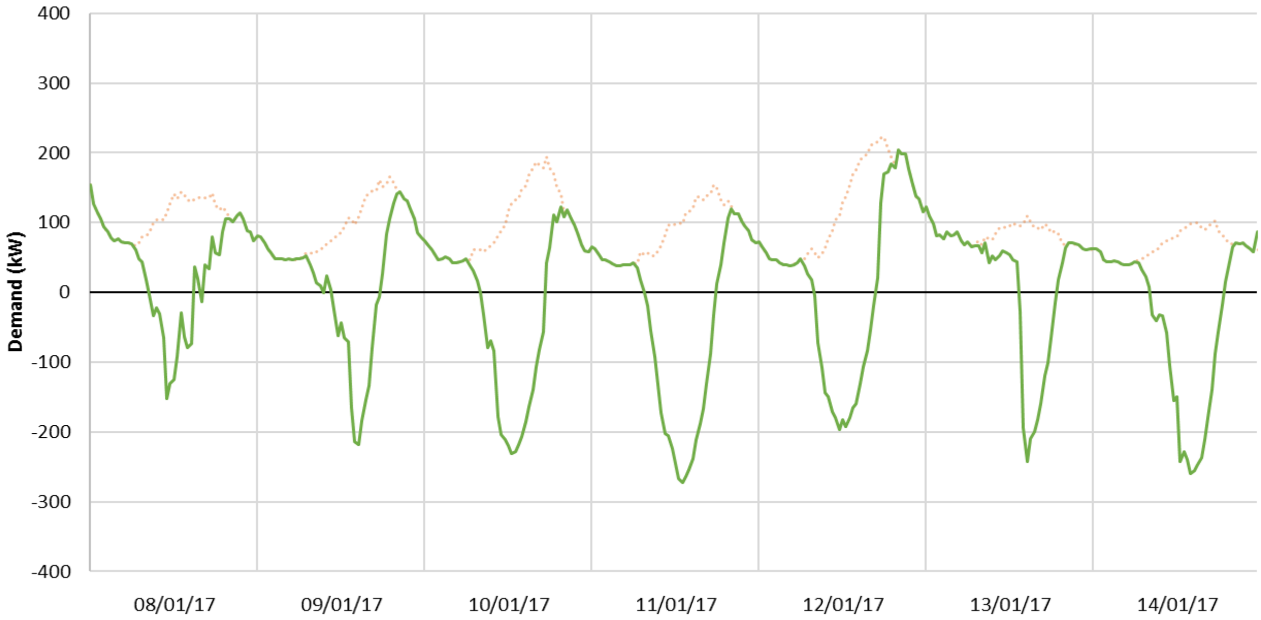


Figure 4 Traditional demand with solar PV, data from Salisbury trial showing large undiversified exports.

This presents a challenge as SAPN has designed its network to account for diversity between customers (i.e. not all customers do the same thing at the same time). Conversely, all customers' solar PV systems in the same local area are generally exposed to the same levels of solar irradiation, meaning they all generate and export to the network simultaneously. In mild weather, underlying load on the local network can be incredibly low, and therefore this undiversified solar generation becomes significant export and reverse power flow. This, along with the fact that uptake of DER is not typically uniform resulting in clustered hotspots on the network, means that hosting capacity breaches are highly locational and challenging to forecast.

The aggregation of battery systems in VPPs can present significant value to customers and the energy system, but will also present further challenges to diversity. A VPP operator who triggers the simultaneous discharge of multiple batteries in the same local area, for example in response to a market price signal, can cause a very large swing in energy flow in the local network.

The effect of this undiversified VPP orchestration can be seen in Figure 5.

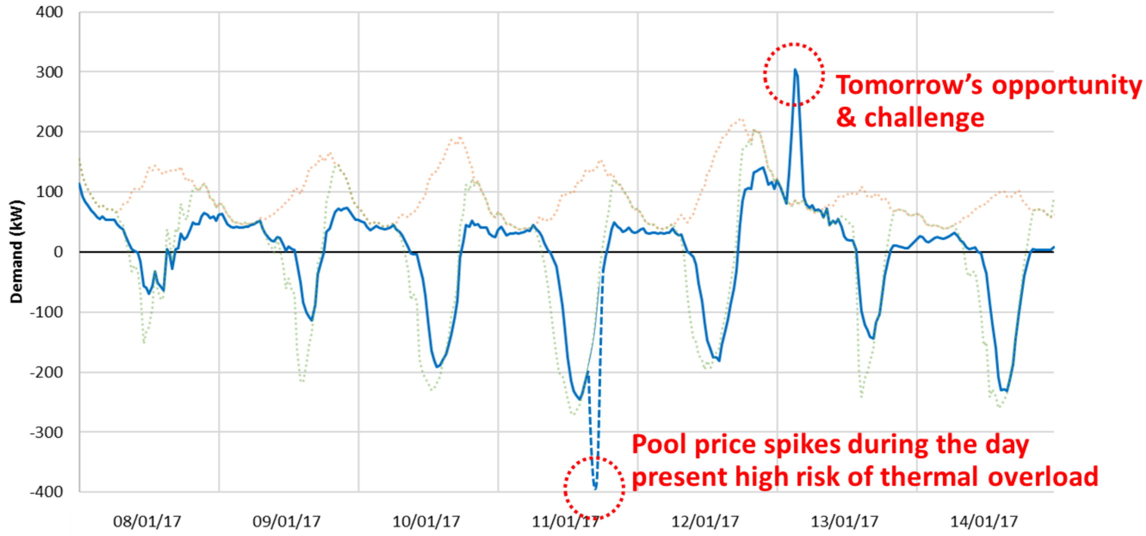


Figure 5 Traditional demand with solar PV and battery orchestration as VPP, data from Salisbury trial showing large undiversified exports

The third form of DER that is considered within this strategy is electric vehicles. At present, the uptake levels are low in South Australia, but the 2018 AEMO forecasts for EV uptake show that this is set to increase. According to data gathered in large EV projects in the UK, the demand drawn by electric vehicles tends to hit a peak in the evening once customers return home. This will not be coincident with solar generation, leading to potentially very large local demand and voltage swings throughout the course of a day. The impact of the potential increase in EV load has been taken into consideration in all the options considered in this work.

In summary, the increased levels of DER have a significant influence on:

- Network diversity
- The direction of power flow in the network
- The predictability of energy flows on the LV network

The effects of these factors are:

- Voltage moving outside of statutory limits on the LV network
- Transformers becoming thermally overloaded in the reverse direction

These consequences can compromise the safe and secure distribution of electricity in the local network. If these effects are not adequately managed at LV, there are likely to be trickle up effects leading to constraints occurring on higher voltage networks.

SAPN is investigating and has implemented some initial passive measures to increase the hosting capacity of the network:

- **Inverter voltage response modes:** In December 2017, SAPN mandated the Volt-VAr response mode described in AS4777.2[1] for all new inverter solar and battery systems connected to the network. This response mode leverages the reactive power capability in modern inverters to assist with lowering the voltage on the local network. To be truly effective, the majority of the customer inverters on the local LV network will need the feature enabled, so the benefit will grow over time as old inverters are replaced.

[1] AS/NZS 4777.2 2015 Grid connection of energy systems via inverters Part 2: Inverter requirements

- **New tariffs:** SAPN is proposing new tariffs for the next regulatory period which will encourage customers to shift load to the middle of the day to help mitigate the effects caused by excess solar generation
- **Shifting hot water load:** SAPN is looking at how it can expand trials for shifting hot water load into the middle of the day to absorb excess local solar generation.

These passive measures have all been considered as part of the baseline when developing and assessing the various strategic options assessed in this document.

2.2 Current state of LV network design, management and operations

The vast majority of SAPN's customers are connected to the LV network (approximately 850,000 customer connections in comparison to less than 100 at HV). The LV network is extensive, with over 32,500 km of installed overhead lines and underground cables, representing 20% of the entire installed asset base across SAPN's network. However, due to the historical predictability of consumer loads and one-way power flows, the LV network has not been actively managed. As a consequence, there is poor visibility of the LV network, being largely unmonitored and with limited asset information (absent, incomplete and/or erroneous).

The reason for this is that, historically, SAPN (in common with other network operators globally) observed that:

- The majority of LV network consumers wanted to import power with only a small minority wanting to export power.
- Many LV customers have similar daily usage electricity cycles but varying slightly in time.

Consequently, LV network management costs have been kept low as a result of the following:

- **Decentralised design:** Due to the past simplicity and low complexity of the LV network, the technical design approach was historically left to the local depot, resulting in area-specific design features.
- **Limited capture of asset information:** Because of the simple design and planning approaches described above, and the fact that the LV network traditionally "just worked", detailed information about the electrical characteristics of LV assets have not been recorded.
- **Simplified forecasting and planning:** Predictability of customer demand and diversity meant that simple design rules could be used to plan the LV network, in place of time consuming network simulation.
- **Reactive quality of supply management:** To keep costs down, SAPN has historically had no fixed monitoring on the LV network. When a customer enquired about the power quality at their property, SAPN deployed temporary loggers to monitor for the issue and deploy a network remediation if required.
- **Decentralised operations**: Much like LV network design, network operations were managed locally by the depots. This has meant that whenever the LV network has been reconfigured by the local crews, the information about the new network configuration has not been recorded in the centralised operational systems causing the quality of the mapping of customer to asset to degrade over time.

In summary, SAPN was able to use a passive management approach to keep LV management cost and complexity down by leveraging load diversity and the simplicity of only dealing with one-directional power flow. Conversely, the HV network (11kV and above) has always been designed and planned with more sophistication, leveraging detailed asset information and later monitoring to perform detailed network simulations.

With the introduction of high levels of DER, the simplifications and cost reductions afforded by diversity and one-directional power flow no longer hold true. It is therefore necessary to extend SAPN's more sophisticated grid operation capabilities into the LV network. Depending on the strategy selected, this could require the development of new business processes to manage DER, from passive measures such as new connection standards, tariffs and incentives through to active grid management and mediation of orchestrated DER in VPPs.

3. Guiding principles for strategy development

There are a number of factors that must be considered in the development of a strategy for LV management which have been established in accordance with SAPN's regulatory obligations, the National Energy Objective and community expectations that have been expressed through SAPN's stakeholder engagement program. Therefore, the strategies have been developed for SAPN with the following guiding principles in mind:

1. Enable customer choice
2. Highest economic value
3. Optionality
4. No regrets safeguard

Enabling customer choice is achieved by ensuring customers can continue to have the choice to connect and get value from DER, participate in VPPs and other future schemes such as peer-to-peer energy trading. However, this needs to be achieved in a way that creates the greatest net outcome for all customers, not just those with DER. This assessment – the balance of the costs and benefits of various solutions as compared to the network issues – is carried out by a standardised methodology presented by the Transform Model® (detailed in section 1.1).

Optionality is an important consideration when taking decisions against a backdrop of uncertainty. In this case, the uncertainty stems from the lack of clarity on what the precise nature of uptake of DER will be, and what the potential future energy framework and marketplace will look like. The first of these is managed through the consideration of a range of credible future uptake scenarios. This permits analysis to ensure that any choices being made today do not preclude the pursuit of different potential pathways moving forward. It helps to avoid the potential over-investment in network assets that could be made if one was to take a narrow view of the future, anticipating high growth in certain areas, when these assets could in fact become stranded and uneconomic if such growth did not materialise.

Similarly, the industry is undertaking a wide-ranging assessment of the future electricity distribution sector through the Open Energy Networks project (being led by ENA and AEMO). This work is considering three potential future frameworks that could manifest whereby DER will play a more active role in the system of the future. However, it is likely that the ultimate framework that comes to fruition will be a variant of one, or a hybrid of two, of these frameworks. It is therefore crucial that any decisions taken by SAPN in developing the strategy does not bind progress to one particular, narrow pathway, but rather is 'fit for the future' and can embrace the changing landscape.

Hence the strategy needs to ensure that any industry developments through, for example, the increased role of aggregators, non-network solutions and tariff reform, do not conflict with the actions taken by SAPN and mean that customers will continue to experience safe and reliable electricity supply. The strategy must act as a strong foundation on which to build, that will, in and of itself, deliver value to customers, but will also pass the test of being able to accommodate future changes that will enable greater value to be unlocked.

4. Methodology for strategy development

To approach the strategy development, a process was developed which is depicted in 1.1. This process developed a list of strategic choices and assessed the relative costs and benefits of each option under a range of future scenarios. The steps are summarised below and detailed in each of the following subsections.

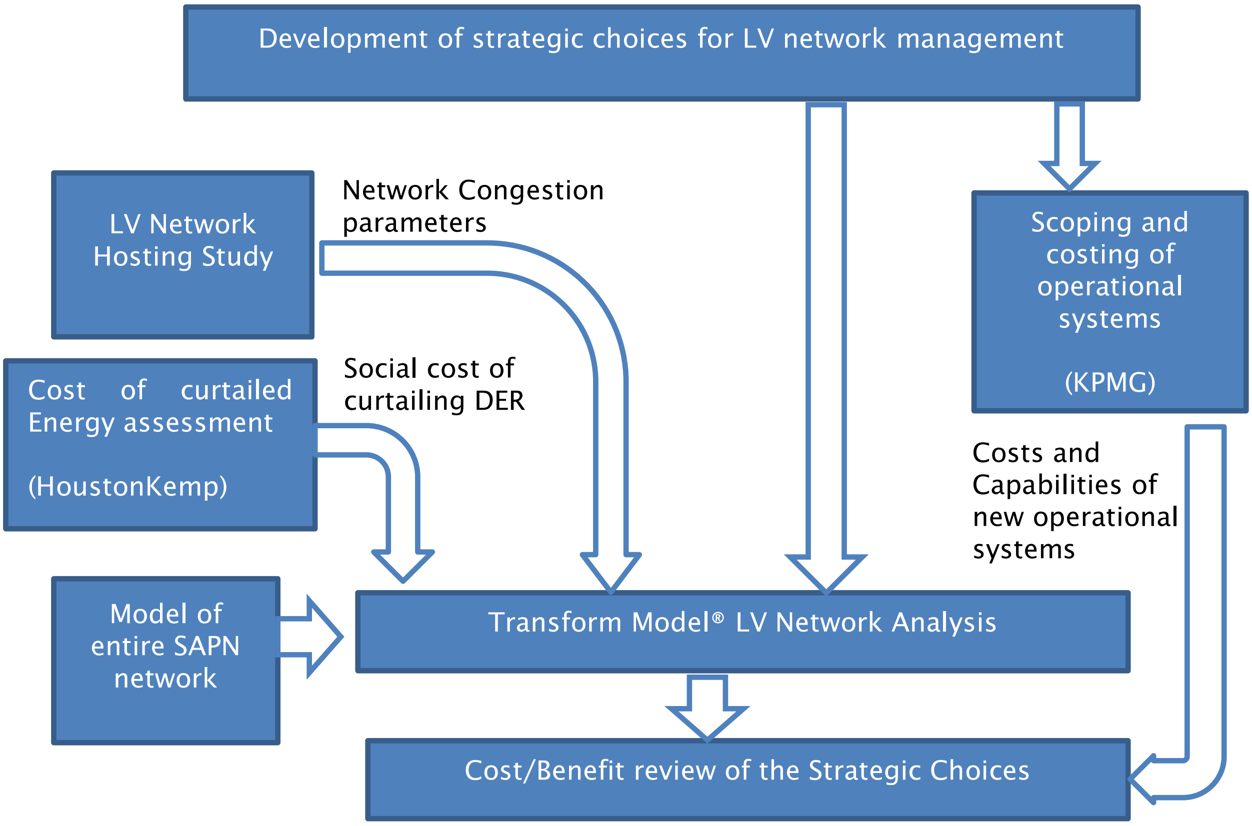


Figure 6 Overview of the strategy development process

1. DER Hosting Capacity Study

An LV network DER hosting study was undertaken to quantify the range of hosting capacities of a representative set of LV network prototype categories. The results from this study feed into the whole of network parametric modelling undertaken in the Transform Model®.

This process is summarised in more detail in section 4.1 and the full methodology and results from this exercise can be found in the separate report.[3]

2. Development of strategic choices

This stage reviews what investment choices SAPN could make and considers the delivery parameters of each approach. The strategic choices that were investigated are fully described in section 4.2.

[3] "LV Management Strategy Annexe 1: DER Hosting Capacity Assessment", EA Technology (November 2018)".

3. **Cost of Curtailed Energy**

To enable a cost-benefit analysis to be undertaken, a view of the cost to society of curtailing DER was required to facilitate the final cost-benefit analysis. SAPN commissioned an independent assessment of these costs and they are discussed in section 4.3.

4. **Identification of new operational systems and capabilities**

While the costs of providing dynamic export limits, and of intervening through network augmentation or non-network alternatives have been identified in the previous stages; alternative approaches introduce different forms of costs.

For example, to deliver the benefits of a dynamic approach to LV network management there needs to be investment in new capabilities. This part of the process assesses the functionality and costs of any new operational systems and processes which would be required to deliver the strategic option under consideration.

The range of platforms and their cost assumptions are introduced in section 5. The costs introduced within the section for operational systems were developed jointly between SAPN and KPMG in response to the functional requirements set out in the strategic choices phase of this process.

It is observed that these costings include both upfront capital costs as well as operational costs. Some of the operational cost headings associated with the establishment of various platforms have been based upon assumptions regarding the number of active DER users and the rates of growth of these users. It should be stressed that this feature would allow SAPN to flex operational costs to match the number of users who are using any DER management platforms. This is a cost opportunity that cannot be offered by strategic options that are dependent on installing network infrastructure as these costs would be stranded in the event of the network being underutilised whereas the platform approach allows operational costs to be trimmed in the event of underutilisation.

5. **Transform Model® network analysis**

The Transform Model® holds a parametric representation of the entire SAPN LV network. This model is used to quantify the impact of DER uptake on the broader LV network and applies an optimal mix of the various hosting capacity improvements such as transformer re-tapping, transformer replacements, LV STATCOMs, a range of demand side non-network solutions and static and dynamic export limiting. Each of the potential network-side and non-network interventions are fully costed to allow comparison with other options.

A separate report[5] details the full process and assumptions that were employed in the development of this strategy picture, but a summary of its usage is recorded within section 1.1.

6. **Cost-benefit analysis**

The cost-benefit analysis was the final stage of the process where the costs and benefits associated with each strategic choice were assessed. The approach employed is fully discussed in section 6.

Further detail is provided on the process within each these steps in the following sections.

[5] "LV Management Strategy Annexe 2: Development of the Transform Model", EA Technology (November 2018)

4.1 DER Hosting Capacity assessment

The aim of the hosting capacity study was to determine the maximum headroom available on SAPN's LV network to accommodate the connection of DER before the occurrence of voltage and/or thermal violations.

Network models were created to represent characteristic feeder types from SAPN's network. The points where these networks become constrained under various scenarios were determined by performing several Quasi-Dynamic load flow studies using DIgSILENT Power Factory. For this study, a total of twenty-one individual low voltage (LV), and six 11kV high voltage SAPN distribution networks were modelled. The Quasi-Dynamic analysis was carried out for a period of 24 hours (and 365 days for some selected cases).

The network capacity limits for hosting DER were defined as being the amount of DER connected (in kW per customer) before network limits were breached. This was examined in terms of both voltage limits and thermal (reverse power flow) limits. The results obtained from this detailed analysis formed the inputs to the Transform Model®.

Figure 7 shows the hosting capacity for a number of different LV network types, indicating the range that the capacity could take (in kW per customer, from 0kW to 8kW) before breaching thermal or voltage limits. The chart also shows the existing penetration levels and the forecast for 2025 based on neutral uptake rate.

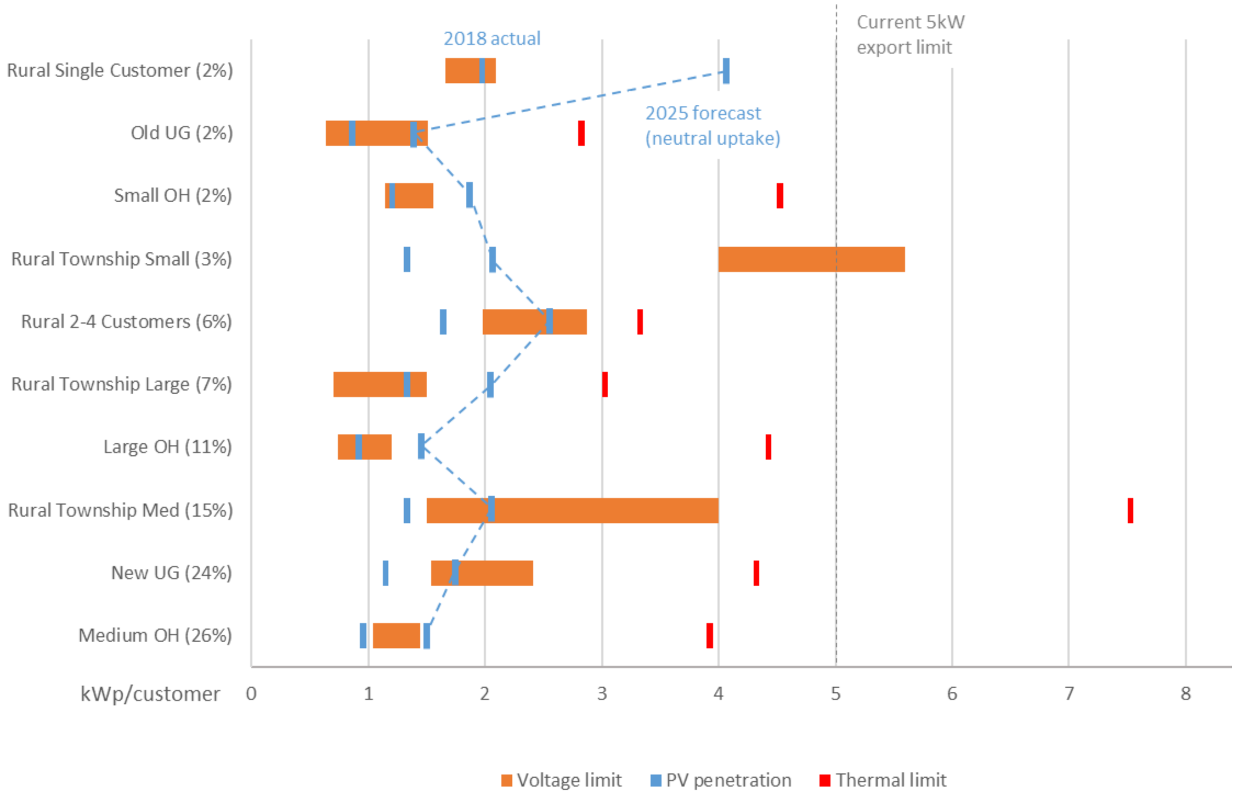


Figure 7 **Hosting capacity (kW export per customer) for different LV network types**

At present, the approach adopted by SAPN is to permit 5kW export per customer, but it is clear that the hosting capacity on a per customer basis is considerably less than 5kW for the majority of the network types present in SAPN's network and in some cases the capacity can be as low as 1 – 2 kW.

Further details on the hosting capacity assessment conducted for SAPN can be found in "LV Management Strategy Annexe 1: DER Hosting Capacity Assessment".

4.2 Development of Strategic Choices

Within this stage, work was undertaken to decide what approaches might be feasible to ensure to manage hosting capacity and quality and reliability of supply on SAPN's network. This section aimed to generate the set of credible strategic options with consideration to the guiding principles (set out in section 3) so the relative costs and benefits could be assessed by the Transform Model®.

The strategic choices that were developed are introduced in Figure 9 (within section 5) and fully described in section 5.

4.3 Cost of Constraining DER export

To facilitate a cost-benefit analysis the Transform modelling exercise calculated the amount of constrained export[7] to the network that would be faced by DER across each strategic option and investment scenario.

When a constraint is imposed on DER exports, an increase in the dispatch of centralised, grid-sourced generation (coal, gas, wind etc) would be required to maintain the system's supply/demand balance. This change in generation source results in a change in generation cost which has been quantified by HoustonKemp using a methodology consistent with the 'whole of market' approach described in the RIT-T framework. The approach taken assesses the change in fuel cost when displacing zero fuel cost rooftop PV and storage with other zero and non-zero fuel cost generation. The full detail of the HoustonKemp methodology and results can be found in their report[8].

The values recommended by HoustonKemp to assign to constrained DER exports can be found in Figure 8. These values (in $/MWh) are multiplied by the forecast magnitude of constrained energy from the Transform Model® (MWh) to calculate the total market impact of constraining exports under a given strategy.

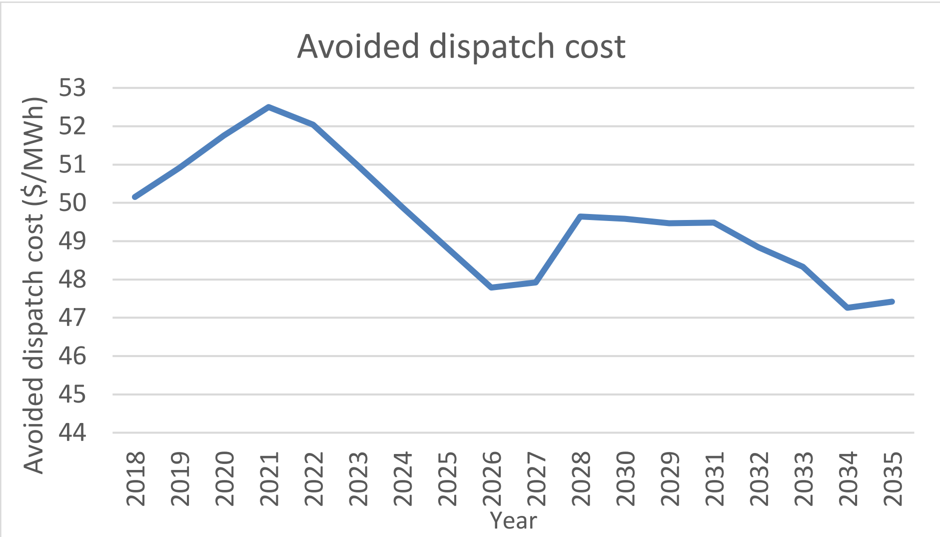


Figure 8 Avoided dispatch cost by enabling DER exports

[7] Network capacity limits blocks access of DER to the system meaning that it cannot export its true energy generation potential. This means that network capacity limits have the effect of blocking the wholesale market from accessing the resource and benefits implied by DER connected to the LV network.

[8] "Estimating avoided dispatch costs and the profile of VPP operation – a methodology report", HoustonKemp, (July 2018)

4.4 Transform Model®

The Transform Model® [9] presents a parametric model of an entire electricity distribution network. This model builds on data from a number of sources, which includes:

- A range of hosting capacities from prototypical representations of different feeder categories
- A range of solutions for improving hosting capacity that a network operator may employ. (This includes network-side solutions, such as new transformers, and non-network solutions, such as tariffs or customer storage.)
- Electricity consumption profiles of different customers classes
- Generation/demand profiles of varying solar PV, battery storage and electric vehicle behaviour
- Uptake rates for different DER (incorporating solar PV generation, battery storage and EVs)

The Transform Model® then overlays the anticipated future demand that will be placed upon the network from various DER, based on forecasts published by AEMO in the 2018 ISP[10]. In instances where network feeders breach their hosting capacity limits, the Transform Model® simulates the technical and economic choices that a network operator will have to make to resolve the hosting constraint.

The model is tested against varying sensitivities to reflect the uncertainty in future DER uptake and future consumer behaviour. This assessment ensures the chosen strategy is tested and found to be appropriate against a range of possible future states. The full set of sensitivity cases modelled can be found in Table 1.

Table 1 Transform Model future scenario sensitivities

Case	PV installed capacity (MW)	EV penetration (vehicles)	Energy Storage (MW)	VPP participation
Neutral-45	AEMO ISP 2018 **neutral** growth forecast	AEMO ISP 2018 **neutral** forecast	AEMO ISP 2018 **neutral** with the assumption of 40,000 state government batteries staged as per current plans	45%
PV Strong-45	As above	AEMO ISP 2018 **weak** forecast	AEMO insights 2017 **weak** with the assumption of 40,000 state government batteries staged as per current plans	45%
VPP Strong-45	AEMO ISP 2018 strong growth forecast plus additional PV to be installed under the Tesla VPP project	AEMO ISP 2018 neutral forecast (electric vehicles on the road)	AEMO ISP 2018 **weak** plus 40,000 state government batteries and 50,000 Tesla batteries staged as per current plans	45%
Weak Uptake-45	AEMO insights 2017 **low** - shifted forward 2 years to reflect actuals for FYE 2018	AEMO ISP 2018 weak forecast	AEMO insights 2017 **weak** with the assumption of 40,000 state government batteries staged as per current plans	45%
Neutral-90	AEMO ISP 2018 **neutral** growth forecast	AEMO ISP 2018 **neutral** forecast	AEMO ISP 2018 **neutral** with the assumption of 40,000 state	90%

[9] https://www.eatechnology.com/engineering-projects/the-transform-model/
[10] "Integrated System Plan", AEMO (July 2018)

Case	PV installed capacity (MW)	EV penetration (vehicles)	Energy Storage (MW)	VPP participation
			government batteries staged as per current plans	
Neutral-10	AEMO ISP 2018 **neutral** growth forecast	AEMO ISP 2018 **neutral** forecast	AEMO ISP 2018 **neutral** with the assumption of 40,000 state government batteries staged as per current plans	10%
VPP Strong-90	AEMO ISP 2018 strong growth forecast plus additional PV to be installed under the Tesla VPP project	AEMO ISP 2018 neutral forecast (electric vehicles on the road)	AEMO ISP 2018 **weak** plus 40,000 state government batteries and 50,000 Tesla batteries staged as per current plans	90%
Base	Blend of Neutral-45 (70%), Neutral-10 (15%), VPP strong-45 (15%)			

The Transform Model® was used within this analysis to simulate the effect of each strategic choice, across all scenarios and sensitivity cases, upon:

- The cost of conventional network interventions (i.e. wires and transformers) and non-network solutions associated with each strategic choice; and
- The magnitude of constrained DER export in MWh under strategies where this applies.

The full methodology and assumptions that were used in the Transform Model® analysis are recorded in a separate report.[4] Some of the key assumptions that the Transform Model® analysis employed for this basic background assumptions process are as follows:

- Demand profiles of customers were taken from SAPN's real-world data
- A range of network solutions and their associated costs and benefits were defined through engagement with SAPN's design and planning engineering staff
- A number of non-network alternatives to resolve hosting capacity were defined
- Profiles of various DER, including PV export, were taken from SAPN's real-world data. In cases where such data did not exist (e.g. EV charging profiles), then real-world data from other networks were used.
- Inverter response through compliance with AS4777.2 was modelled on all new systems, along with replacement systems that were modelled as becoming active once existing systems reach anticipated end of life.

Assumptions within the Transform Model® that are specific to each strategic option are fully described in section 5.

5. Strategic options

There is growing recognition at the national policy-making level that networks companies need to be prepared to help optimise the value proposition from DER. As an example of this, the Australian Electricity Market Commission (AEMC) in their recent review of the regulatory framework[11] states an expectation that "the operation of the grid will need to be more sophisticated to efficiently integrate DER and to manage challenges to avoid network and system security issues".

At the start of this project, a workshop was held to develop an array of different strategic directions which could be employed to ensure that LV network operations enable DER in such a way that maximises value for all customers. The investment strategies arrived at from this process are summarised in Figure 9.

Static limits

- When an LV network reaches a certain PV installed capacity, all new customers who wish to connect DER to that network will be limited to a zero or near-zero export limit.
- Because new DER customers export is capped, no network augmentation is required
- Capped DER customers cannot access feed-in tariffs or participate in VPPs. This reduces the value to the DER customers themselves and also reduces the broader market benefits enabled by solar PV and VPPs.

Increase network hosting capacity

- 5kW export limit per customer is retained
- The optimal combination of network and non-network solutions are used to avoid curtailment of DER and power quality issues
- Cost of increasing network hosting capacity are offset by there being no requirement to curtail DER

Fully Dynamic Model

- Capability to provide a dynamic export limit to manage DER output
- Dynamic export limits are based on building a full electrical LV network model
- This model assumes no requirement for additional network augmentation, but will occasionally constrain DER when the model assesses the network to be under stress (to a much lesser extent than a static limits approach).

Dynamic Template Model

- Capability to provide a dynamic export limit to manage DER output
- Available capacity upon each LV network is assessed using a template model (prototypical network categorisation) approach.
- This model assumes no requirement for additional network augmentation, but will occasionally constrain DER when the model assesses the network to be under stress (to a lesser extent than static limits, but a greater extent than the fully dynamic model).

Figure 9 Summary of strategic options

[11] https://www.aemc.gov.au/markets-reviews-advice/electricity-network-economic-regulatory-framew-1

Each strategic option is a composite of five concepts defined in Figure 10. Each strategic option fulfils these requirements using different methodologies of varying complexity.

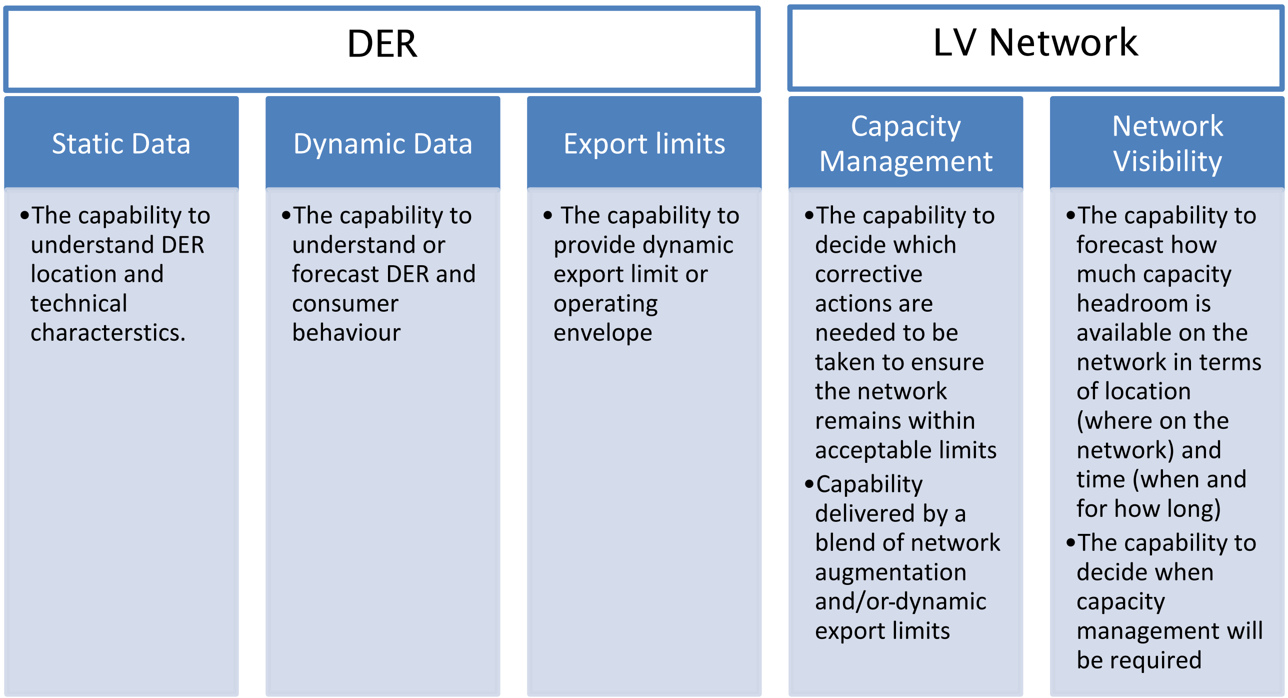


Figure 10 Components within strategic options

Each strategic option introduced in Figure 9 is fully described in the following four sections.

5.1 Static Limits

5.1.1 Static Limits Strategy - What is it?

Using static limits is an approach to managing the output of DER to ensure that the network remains within hosting capacity limits without having to invest in new network capacity or any form of smart network capability. The key features of this approach are summarised in Figure 11.

DER			LV Network	
Static Data	Dynamic Data	Export limits	Constraint Management	Network Visibility
• None gathered	• None gathered	• Once the LV network reaches a certain DER installed capacity, new customers' connection to that LV network would be capped at a very small or zero export limit • The limits are set at time of customer connection and are not updated	• Customers connecting prior to the network reaching capacity would be able to export at 5kW • New customers connecting after the hosting limit is breached would still be able to connect but be limited to a zero or very low to zero export limit.	• None • Without adequate visibility, the hosting capacity limits of networks would need to be conservative and coarse (not network specific) • Coarse network limits do not make best use of available network capacity.

Figure 11 Summary of Static Curtailment features

In this approach, when an LV network reaches a certain PV installed capacity, all new customers who wish to connect DER to that network will be limited to a zero or near-zero export limit. In lieu of greater LV network visibility, the hosting capacity limits for the LV networks will need to be set in a conservative and coarse way. For example, the network may only be in breach of hosting limits for a short period of time in Spring but new DER customers will be constantly limited in export using this static approach. This means that, while the network is technically capable of accepting export from DER for most of the year, customers connecting to constrained LV networks will be limited all year round. This approach is taken with the intention of avoiding mass augmentation of the LV network required to support high DER uptake.

This behaviour is depicted in Figure 12, which illustrates the inefficiencies in over-curtailment with this approach.

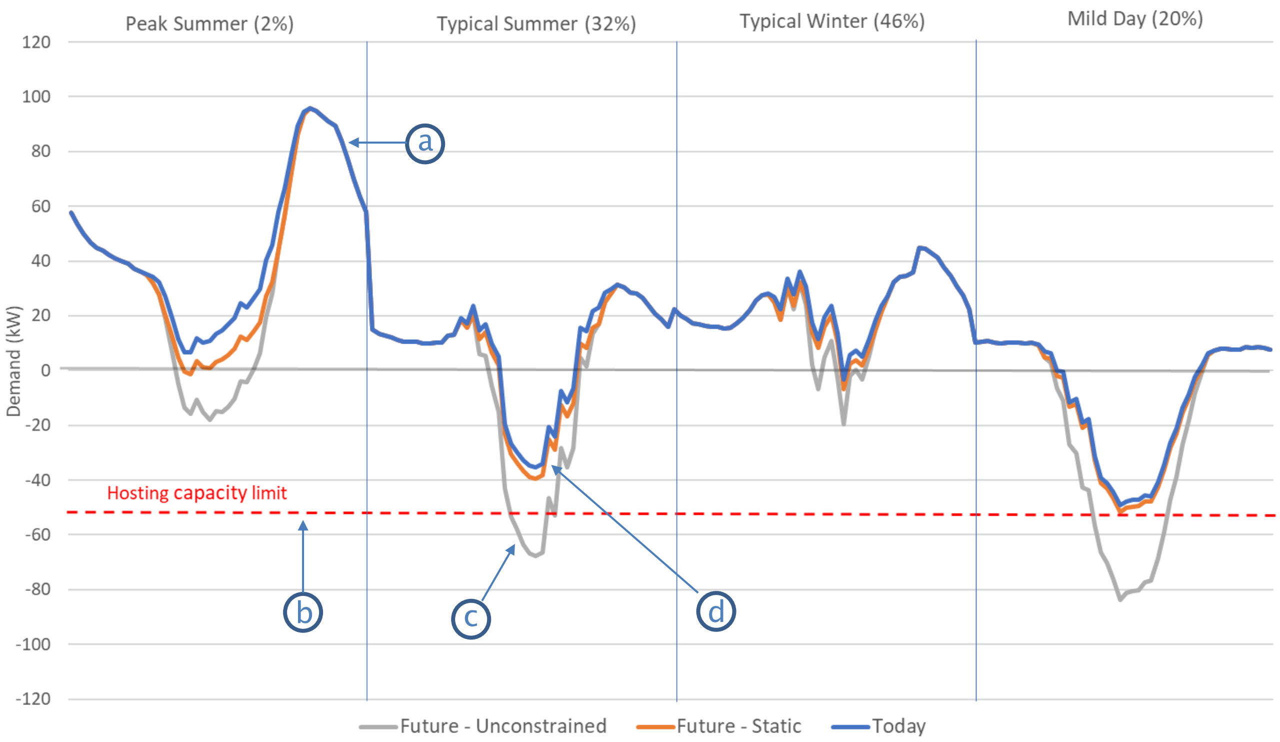


Figure 12 The action of a static curtailment limit upon customers

The figure shows:

a) An example net demand profile of a small transformer over 4 different characteristic days in 2018. The percentages in brackets next to each representative day label is the percentage of the year that each type of day represents in South Australia. This illustrates the high demands experienced on a peak summer day, and the large exports experienced on mild and typical summer days.

b) The estimated hosting capacity limit which dictates the maximum amount of DER that can be installed on the LV transformer before the physical limits of the transformer and conductors are breached. Under this strategy, there is no improved network visibility, so this limit is a coarse, conservative estimate only.

c) The net demand profile of the transformer in the future, as the DER penetration increases. The reverse power flows on the transformer will exceed the hosting capacity limits during certain periods of the year.

d) The orange line on the chart represents the future net export profile with a small number of additional customers for the transformer under the static limits strategy. Under this strategy, once the installed DER penetration reaches the estimated hosting capacity limit, all new DER customers are statically limited to zero or near-zero export for the life of their DER system.

The difference between the grey and orange line represents the exports that would be lost from export limited customers by moving from an unconstrained future to a future where the static limits strategy is deployed.

As this strategy has no increased investment in network visibility, the following challenges in implementation are anticipated:

- Hosting capacity limits will need be estimated broadly, leveraging limited asset, power flow and voltage data. This will result in conservative limits that do not make effective use of real available network capacity.
- Without increased telemetry, it would be challenging to manage compliance with export limits. This may result in the need for expensive network upgrades where export limits are not followed.
- New DER customers limited to zero export would not be able to effectively participate in VPPs, which will likely result in worse financial outcomes for all customers.

Feedback from customers and industry, including the AEMC suggest that *"prohibiting new DER systems from exporting where local hosting capacity has been reached or imposing broad restrictions is unlikely to be efficient or to meet customer expectations".*

For the purpose of the cost-benefit analysis, it will be assumed that zero cost solutions can be found to the first two of these options. This means that the use of this model for static limits is likely to overestimate the net benefits of a static limits approach.

5.1.2 Static Limits - Cost and delivery components

The delivery components for this approach would be a hosting capacity study to decide on the limit to the amount of DER that could be installed on a transformer before breaching network limits. This strategy would seek to minimise capital and operational expenditure by minimising the extent of this modelling exercise through modelling a small sample of transformers.

There would also need to be an upgrade to the DER connection process which would link the customer to the transformer and assess whether the customer's proposed connection would exceed the allowed DER capacity on the transformer. The customer would then be issued a static export limit that would need to be applied by the DER installer.

The key cost that characterises this approach is the sacrificed opportunity cost associated with restricting the access of new DER on constrained networks from exporting energy. This cost would be experienced by all customers as additional, zero or non-zero fuel cost generation would need to be dispatched into the NEM to account for the constrained export. This concept is explained in more detail in section 4.3.

5.1.3 Static Limits - Operational features

A Static Limits approach would have minimal operational features for the network operator. The operational burden is passed onto third parties who would be responsible for ensuring that export limits are loaded into DER systems upon commissioning.

5.1.4 Static Limits - Investment risks

In principle, this strategy is expected to replace the costs of investment in LV network augmentation for the costs of constrained energy.

In practice, it seems likely that the choice of a static limit to be applied on an enduring basis is unlikely to avoid all problems. If this were to be the case, then there would still be a requirement for the network operator to fund an ongoing quality of supply programme to respond reactively to power quality issues and fix them using conventional approaches.

5.1.5 Static Limits - Opportunities for additional value streams

Because this approach does not require any tools that improve network visibility, control or information dissemination it is hard to show any additional value streams created by the Static Limits approach.

As the limits of the network will not be known in a locational or real-time basis, then this approach acts as a barrier to the use of non-network solutions to mitigate LV network capacity issues.

5.2 Dynamic Templates

The Dynamic Templates Strategy

The dynamic templates approach represents an investment strategy which seeks to deliver a capability that allows SAPN to:

- Enable automatic registration of DER.
- Calculate the maximum allowable DER export based on a template model of LV feeders rather than individual models of each LV feeder.
- Apportion the available headroom per feeder and communicate the allowable export to customers.

In comparison to the Static Limits strategy, the Dynamic Templates approach provides the following capability enhancements:

- Instead of providing one constant and enduring export limit per connection for all time, this strategy varies the maximum export limit on a near-real time basis where required.
- Instead of providing one static export limit that is applied in common across all LV feeders, the Dynamic Templates strategy can distinguish between categories of LV feeders and apply a different limit per feeder.
- While the export limit will need to be reduced at times when the network is under stress, it is anticipated that for the majority of time the export limit will be higher than that under the Static Limits approach (reflecting the real operational state of the network), increasing value to consumers and improving utilisation of the assets.

The overall features of dynamic templates are summarised in Figure 13 below.

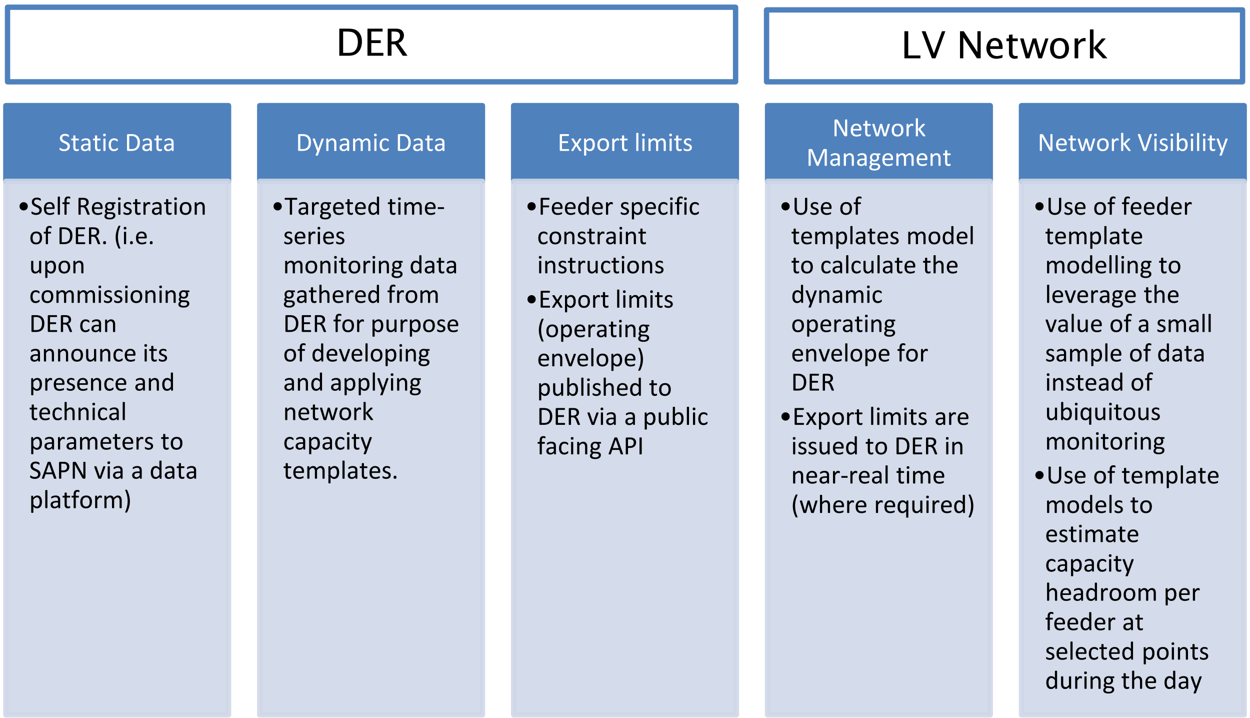


Figure 13 **Capability summary for the Dynamic Templates strategy**

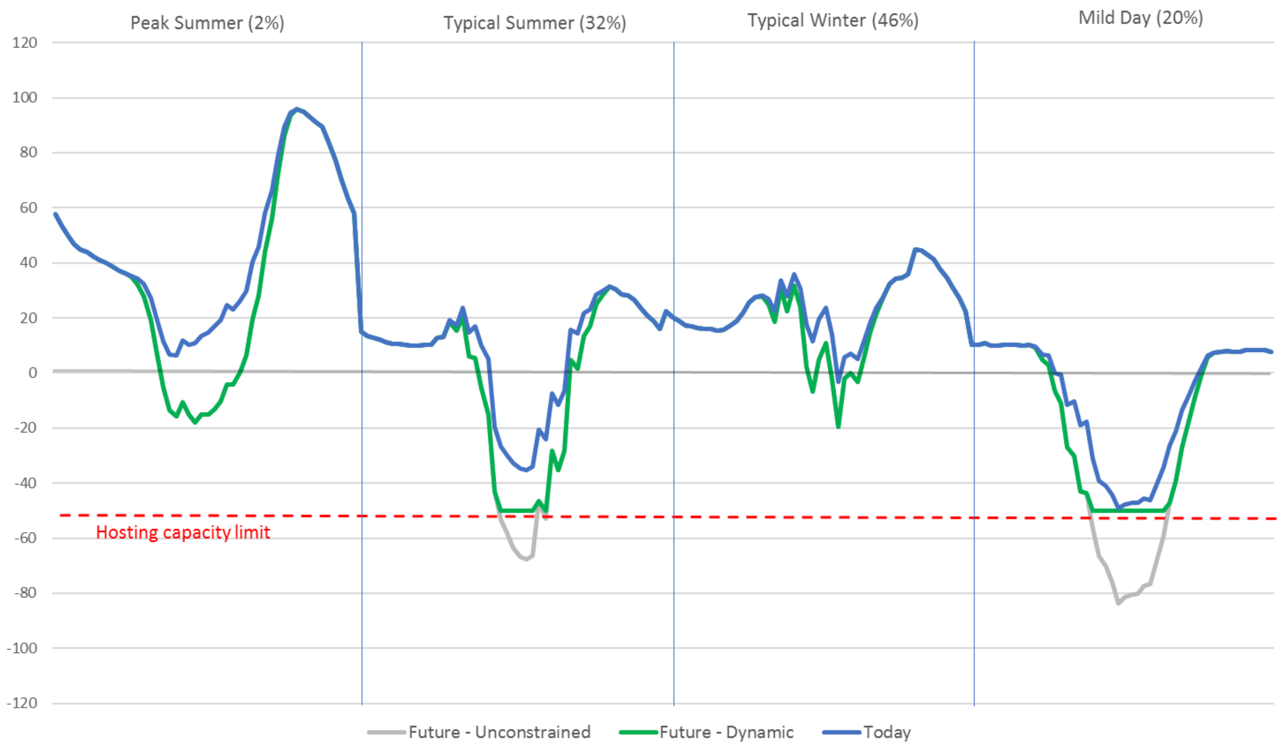


Figure 14 **Illustration of application of limits in the Dynamic Templates approach**

Figure 14 shows the same demand profile of an LV transformer over a series of characteristic days as describe in Section 5.1.1 and Figure 12. The new green line represents the future demand profile of the transformer under the dynamic limits strategy, where export is only limited at times when the network is under stress. The difference between the grey and green line represents the energy lost through the dynamic export limiting versus an unconstrained future.

Unlike the Static Limits and Network Augmentation strategies, delivery of this strategy requires the development of new capabilities.

5.2.1 Dynamic Templates Strategy - What is a template model?

The most accurate approach to the calculation of the remaining capacity upon the part of an electricity network is to construct a full network model in a distribution management software environment leveraging real-time, time-series monitoring sources. Such packages can be used in curtailment calculation engines which conduct a continuous assessment of the available capacity on individual feeders based on near real-time network state estimation. Establishment of such a curtailment engine requires a complete electrical LV dataset as well as a near-real time operational view of the network state, neither of which SAPN has access to.

An alternative approach to bespoke network modelling is to use a template approach to calculate remaining hosting capacity. Network Templates is a methodology which allows network operators to assess the remaining headroom on LV feeders based on statistical sampling of an overall population without the need for ubiquitous monitoring or modelling, albeit with a reduction in accuracy.

A full introduction to network modelling through the use of LV network templates is provided in Appendix II.

Western Power Distribution in the UK has successfully demonstrated a network templating methodology to achieve these aims. This trial demonstrated that it was possible to forecast capacity headroom on individual feeders to within an accuracy of 20% of the source transformer's rated capacity.

Template methodology, therefore, provides a tool that allows users to:

- Forecast the likely load flows on an LV feeder during characteristic days.
- Understand the average voltage profile that would be experienced by users within the cluster (a small geographic area with a high penetration of DER technologies), in actuality, the users would have access to the entire population curve for voltages at a different time of day.

Accuracy was assessed based on an error in relation to the size of the feeding transformer. Findings showed that overall 90% of the transformers in all clusters can be predicted with an error of less than 20% of its transformer rating. Even if it was desirable to increase the accuracy to 10%, then 70% of substations would still fall within acceptable parameters.

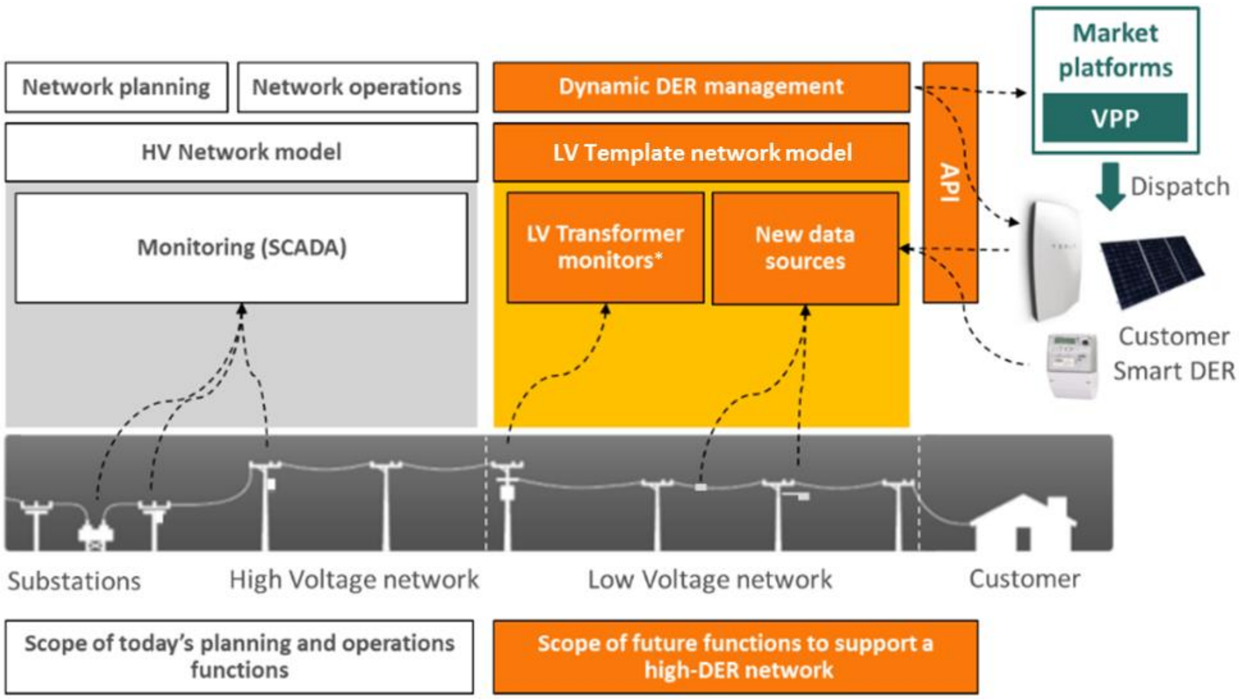
The LV Template approach will not give DER users the maximum possible quantity of network access as it will provide imperfect network capacity calculations, but it would be provided at a lower cost and risk than more complicated solutions. This reduction in precision is warranted if the reduction in cost of implementing this solution outweighs the benefits of greater precision afforded by a more complex but expensive strategy. The template approach provides optionality to transition to a more sophisticated model if/when the enhancement presents sufficient additional value.

5.2.2 Dynamic Templates - Cost and delivery components

The key delivery elements for the Dynamic Templates model are:

- **Visibility of LV network hosting capacity**
    - A template based LV network model to estimate the hosting capacity of each LV circuit on a time-varying basis.
    - Mid-line and end-of-line monitoring in targeted areas (~10%) of the LV network, primarily through procurement of data as a service from smart meter providers and other third parties. This requires new systems to receive, store and process this data.
- **DER register**
    - A database to store information on the distributed energy resources connected to our network, and implement new processes for installers to register the systems electronically.
    - Electronic registration has the additional benefit that it will improve compliance to SAPNs connection standards, in particular the application of the correct inverter Volt-VAR settings, which will help to mitigate local voltage rise issues over time.
- **Open interfaces (APIs)**
    - New systems and interfaces required to publish dynamic export limits to small customer systems and DER aggregators such as VPPs, communicated every 5 minutes on a rolling basis.

These delivery components are shown in Figure 1 below.



* LV transformer monitoring is out of scope for this strategy

Figure 15 **Delivery components for Dynamic Templates strategy**

The cost and delivery components required for delivering these capabilities were developed under KPMG's capability costs workstream and summarised in Table 2.

Table 2 Template model cost elements

	Operational Costs	Capital Costs	Total Costs
Cost to implement dynamic templates over 2020 – 25 period ($2017)	$4.06m	$33.30m	$37.36m

Dynamic Templates – additional benefits

In addition to supporting dynamic export limits, the templating process would provide the network operator with strong insight into the prevailing voltage profile across LV feeders and likely levels of thermal headroom. A practical demonstration of this benefit was from within WPD's Network Templates trial. From this project, WPD was able to improve its voltage management policy and reduce associated network losses. Such benefits were realised without ubiquitous monitoring.

Because this strategy develops an API to publish dynamic export limits to consumers, it establishes a foundation that would enable non-network solutions to be utilised (such as demand side response) and would facilitate the transition of such approaches into business as usual in a cost-effective manner. The strategy also enables the identification of problem areas in the network for investigation and remediation before customers become impacted, and to more efficiently plan and schedule remedial works. Finally, it will also enable better provision of information to customers seeking to connect both small and large embedded generators to the network.

5.2.3 Dynamic Templates - Investment risks

Like most investments faced by other businesses, there is always some risk in the political, economic, social, or regulatory environment that could undermine the returns expected from the investment. This section considers what hazards could undermine the investment performance of the dynamic templates model and how material these risks could be.

Under this scenario, it is considered that the infrastructure and capability developed to obtain network templates would still be valuable as it would still allow insight into LV network behaviour. It is also considered that the infrastructure developed to offer self-registration and dynamic export limit instructions is low risk because the ongoing OPEX spend to host the APIs is influenced by the number of customers using the service, hence economies could be made to reduce the OPEX.

Under this scenario, the value would still be obtained from the LV Network Templates model as it would still provide SAPN with visibility of network congestion. The ongoing OPEX dedicated to managing APIs for self-registration and mediation could be scaled back as these costs are proportional to the number of customers using these services.

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5.3 Fully Dynamic Model

5.3.1 Fully Dynamic Model - What is it?

The Fully Dynamic Model represents a network management approach which seeks to maximise network access to DER without the need for additional network upgrades.

This approach is similar to Dynamic Templates insofar as infrastructure is required to gather DER information and monitoring data and calculate and distribute dynamic export limits through an API.

This approach has more advanced functionality than Dynamic Templates because of the following features:

- Each LV network feeder has a bespoke model contained within a power system modelling package or Advanced Distribution Management System (ADMS). This requires a full LV network electrical dataset and granular detail about the connected customer DER.
- The available export capacity is assessed every 5 minutes and dynamic export limits are communicated to DER every 5 minutes on a rolling basis.
- The network model would base its calculations on measured data and near real-time forecasts on each individual circuit.

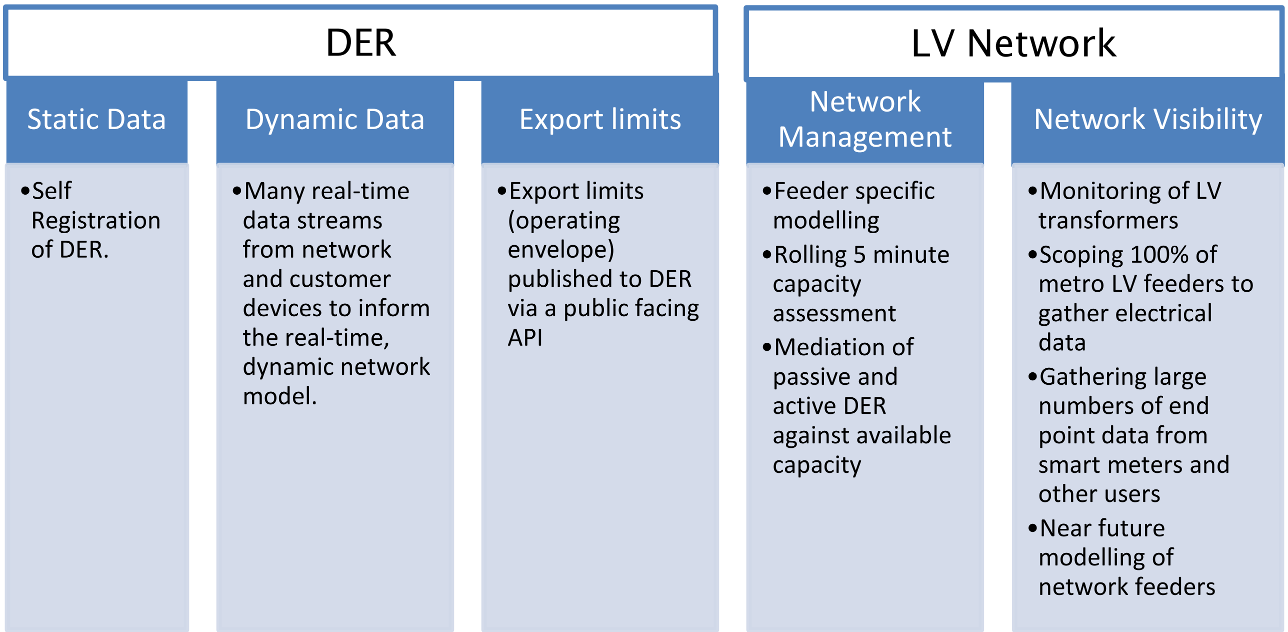

Figure 16 Summary of the capability within the Fully Dynamic Model

5.3.2 Fully Dynamic Model - Cost and delivery components

A summary description of the additional delivery components over the Dynamic Templates model (described in Section 5.2.2) are as follows:

- **Visibility of LV network hosting capacity**
  - Field scoping of the approximately 18,000 metropolitan LV transformer areas to gather electrical data for load flow monitoring
  - Data entry of electrical data for every LV transformer area into the Network Operating Model (NOM)
  - Upgrade of SAPNs ADMS system to the latest version to enable hosting capacity calculations

- Configuration and tuning of the model
- Procurement of mid-line and end-of-line monitoring on near 100% of SAPN's LV transformer areas, primarily through procurement of data as a service from smart meter providers and other third parties.

As the Fully Dynamic Model strategy is a more sophisticated version of the Template Model Strategy, implementation costs are determined by the baseline costs for the Template Model strategy (in Section 5.2.2) plus the costs to implement the more sophisticated model as described above. The total estimated cost to deliver the Fully Dynamic Model Strategy can be seen in Table 3.

Table 3 Fully Dynamic Model cost elements

	Operational Costs	Capital Costs	Total Costs
The cost to implement the fully dynamic network models over 2020 – 25 period ($2017)	$27.70m	$54.14m	$81.84m

5.3.3 Fully Dynamic Model - Investment risks

The Fully Dynamic Model would require a project that was more complicated than a Dynamic Templates strategy. This includes extensive investment in collecting network data and building sophisticated models that may only bring a marginal benefit over using a template based approach.

As the dynamic model is an extended and more sophisticated version of the template model, it is likely prudent that SAPN begins by developing a simpler, template based model and collects data to improve those models over time though opportunistic data capture to improve the precision of the template model. If this approach is taken, there will likely be a time where enough information has been captured this way to transition to a full electrical model of the network which approximates the Fully Dynamic model described here.

5.4 Increase Network Hosting Capacity

This approach is focused on deploying network-side and non-network solutions as necessary to ensure that there is sufficient LV capacity to enable customers to continue to connect DER and export up to 5kW.

For the purposes of forecasting the amount of LV network investment in network and non-network solutions that would be required for this strategy, this analysis makes the assumption that SAPN's existing LV management tools are able to give sufficient visibility to decide where and what capacity interventions are required. This assumption has been made to allow calculation of what is the minimum amount of capital investment into network and non-network solutions required to support this approach.

In reality, it is unlikely that SAPN could achieve this minimum-cost capital upgrade program using existing tools and practices. Further costs would need to be added to make this approach feasible such as simple tools to allow proactive LV network planning to be undertaken. This system could be an extensive LV network modelling package or some form of monitoring.

5.4.1 Increase Network Hosting Capacity - What is it?

DER			LV Network	
Static Data	Dynamic Data	Export limits	Capacity Management	Network Visibility
• No data structures are developed to gather DER static data • Capacity management supported by fixed static data assumptions	• Dynamic data is not gathered directly from DER • Capacity management is supported by assumptions	• None	• Network capacity is improved through a combination of network and non-network solutions to enable DER export up to 5kW per customer	• This approach assumes a reactive approach to network capacity problems. • The investment efficiency of this approach would be enhanced with a network modelling capability to decide where intervention was required. This point is not, however, tested in this report.

Figure 17 Summary of the "No Curtailment" features

5.4.2 Increase Network Hosting Capacity - Cost and delivery components

The delivery components for this strategy would comprise of:

- An infrastructure delivery capability to respond to power quality issues by increasing hosting capacity through an optimal combination of traditional network augmentation approaches and non-network solutions. SAPN already has a capability to deliver network augmentation solutions but a process for assessing when non-network solutions are more appropriate will need to be developed. This will need to be a more lightweight approach than the non-network assessments on the HV network that are used today.
- A trigger capability to inform SAPN of where power quality issues were being experienced. Historically, this may have been reactive (responding to customer queries). However, going forward, this trigger capability will be informed by investments already made outside of this cost-benefit analysis by SAPN in fixed transformer monitors for Quality of Supply purposes. These monitors are being rolled out as part of business as usual requirements that have been justified elsewhere, but their existence will allow for leveraging of additional value and the transition towards more proactive LV management as the roll-out becomes more widespread.

This choice requires no investment in new operational systems to generate and publish dynamic export limits.

5.4.3 Increase Network Hosting Capacity - Network investment risks

The investment risks associated with this approach are that:

- Because this is a reactive approach with no vision of the future, it can only respond to a goal of mitigating "today's" power quality issue. It cannot, however, select the most appropriate mitigation for all possible futures, which could lead to a range of negative outcomes ranging between:

- Inefficient (non-strategic) investment, where an investment is made, but if the underlying growth trend decreases, then the investments would become under-utilised in comparison with the investment appraisal assumed at the time.

- Risk of widespread quality of supply non-compliance due to insufficient investment, where a series of small incremental capacity interventions are taken but, had the true future been known, it would have proven to be more beneficial to make a one-off larger investment early on.

6. Cost-Benefit Analysis

The cost-benefit analysis is the stage where the output from the Transform Model® analysis is joined together with the cost of curtailment assumptions (as per section 4.3) and the cost of any new capabilities that are required by the strategic option. Each strategy was described in terms of three cost headings that are introduced in Table 4. Figure 18 shows an example of this.

Table 4 Cost categories for strategy assessment

	Cost of DER management platforms	Cost of increasing network hosting capacity	Value of unconstrained energy (relative to static DER management)	Net Position
Description	Net present cost of the operational systems required to gather DER data, model the network, make decisions as to where and when constraints will bind and communicate these dynamic export limits to DER systems. For some strategic options, this field will remain zero.	Capital and operating expenses of increasing network hosting capacity to support DER uptake and export. This value includes the lowest cost combination of network and non-network solutions as determined by the Transform Model. For some strategic options, this field will remain zero.	This category records the value of additional PV exports enabled by relieving a network constraint. Where this figure is positive, it has created value in comparison to retaining static limits.	This is the net of: -The cost of the DER management platform, -The cost of any network augmentation -The value of any unconstrained energy In cases where the result of this figure is positive, the strategic option provides better value than the Static Limits network management option.
Source of costs	KPMG platform costing workstream (Future Network Strategy – Technology Costs)	The output from the Transform Model®	The output from the Transform Model® and cost of DER curtailment index determined by HoustonKemp	Net overall value

In order to illustrate the relative costs and benefits of each approach, it is necessary to choose a base case from which they can all be judged. The “Static Limits” option has been chosen as it is seen as the closest to a credible “do nothing approach” which can be implemented at virtually zero cost to SAPN.

Using this approach, the other options are incurring benefits from relieving constraints on DER exports over a static approach which are represented by the yellow bars in Figure 18.

This approach simplifies graphical interpretation as it clearly indicates when the strategic option being considered is better value than the Static Limits base case option, as shown by whether the net position marker is positive or negative with respect to the Static Limits approach (see Figure 18).

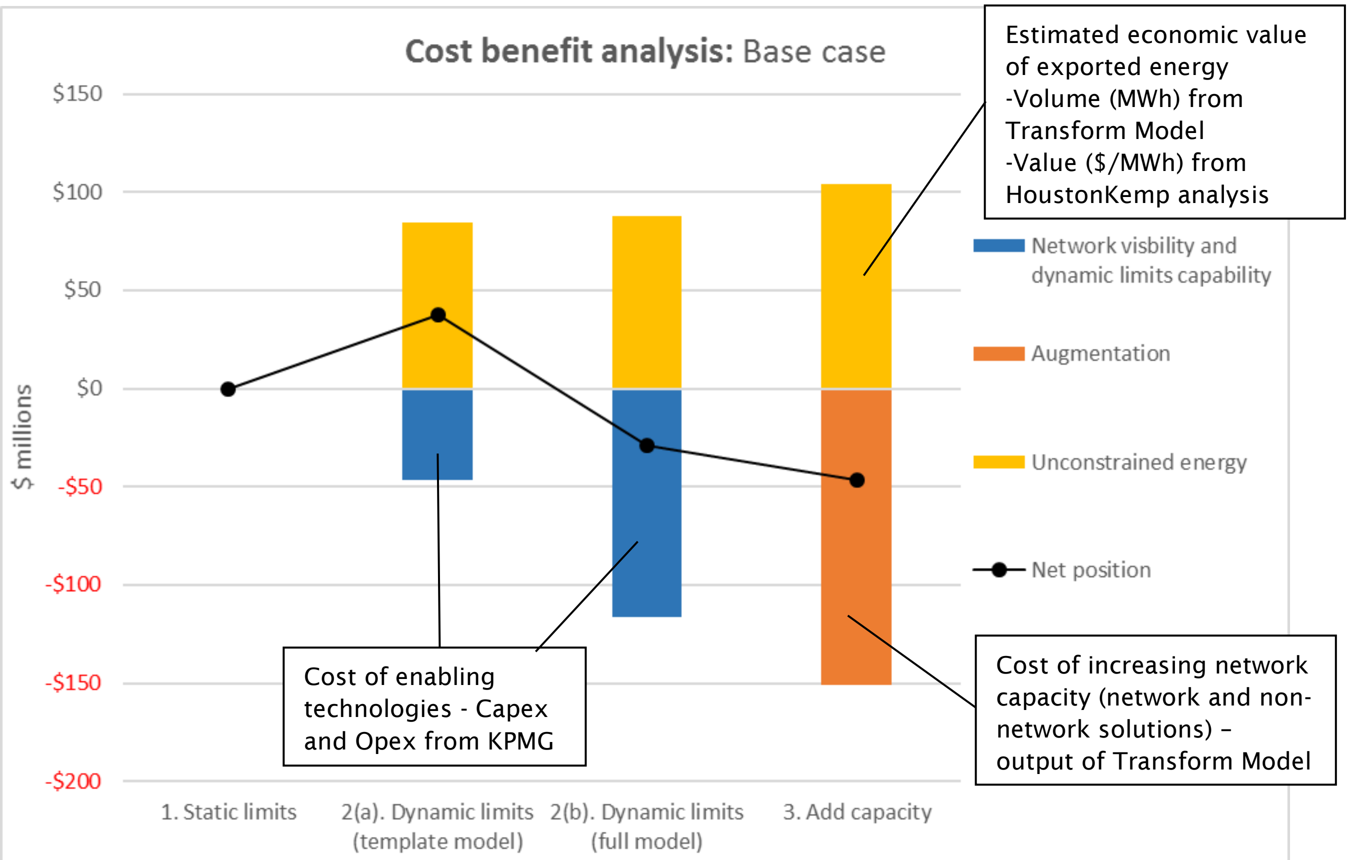

Figure 18 Graphical review of strategic options (single growth scenario)

In all cases, the costs of curtailment, capability costs and augmentation costs were forecast on a year by year basis between 2020 and 2035 and each cost category was expressed as its net present cost using a discount rate of 2.89%, as advised by SAPN, with respect to the cost of capital.

The dynamic capability will be developed between 2020-2025 and will be made available as soon as it has been established. Therefore, benefits will be unlocked as additional functionality is enabled rather than necessarily all coming at the end of a full development process. As value will continue to be unlocked/constrained for the life of the strategy implemented, It is necessary to look beyond 2025 to consider the benefits quantification; and hence 2035 has been taken as a reasonable time horizon over which to compare investments.

It has already been mentioned that each strategic option would be tested against the range of growth forecasts and sensitivity cases described in Table 1. In total there are seven individual cost-benefit assessments which describe investment performance in each sensitivity case.

The significance of being able to review investment performance across different growth forecasts is important as it allows judgement to be made regarding how reliable each strategic option will be in delivering value against future uncertainty.

7. Results and observations

7.1 Base Case

The results for the cost/benefit comparison in the base case is shown below.

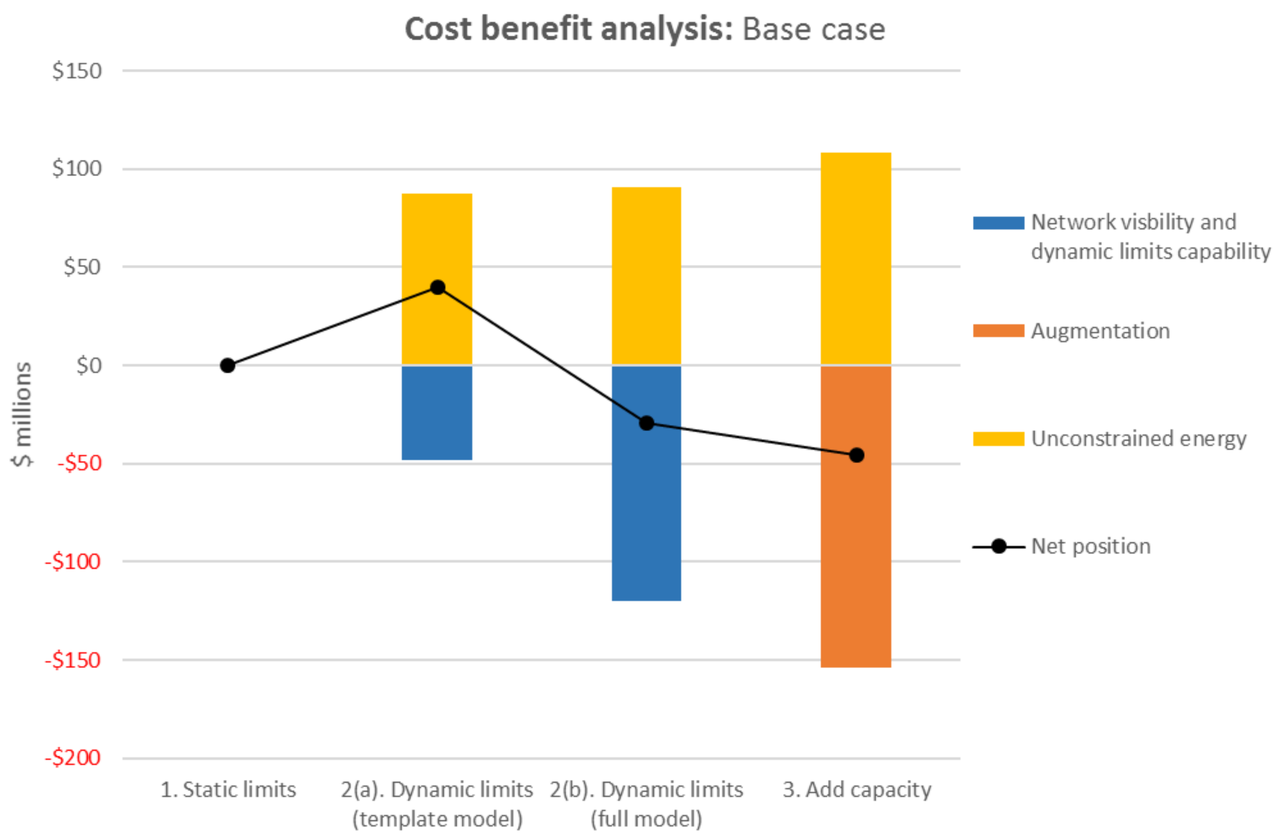

Figure 19 **Cost benefit performance under base case analysis**

In Figure 19, as previously explained, option 1 (Static Limits) is considered as the 'do nothing' or baseline option. The costs and benefits of the other options are presented relative to this baseline as follows:

- For option 3 (Add Capacity) the negative orange bar represents the total expenditure that would be required (NPV to 2035) to add enough capacity to allow all new DER systems to connect with the current export limit of 5kW per customer. This is calculated by the Transform Model® based on the least-cost series of investments required year-on-year to mitigate hosting capacity constraints as they arise, drawn from a set of known technical solutions that includes 'traditional' network augmentation options e.g. changing transformer taps, installing voltage regulation equipment, upgrading transformers, etc., as well as non-traditional solutions such as grid-connected batteries and third-party network support contracts. For each candidate solution, the model knows the cost of the solution (CAPEX and OPEX), the expected technical efficacy in increasing hosting capacity 'headroom', the lifetime of the solution, and so on. The model also takes into account the positive impact of new inverters with Volt-VAr response modes, which become progressively more prevalent through new system installations and also end-of-life inverter replacements, and the potential impact of load shifting due to new tariffs.

- The positive yellow bar for option 3 represents the total value of the additional energy exported to the grid that would, under option 1, have been curtailed due to zero export limits. This energy arises both from passive solar PV and from battery exports due to VPPs dispatching in response to wholesale market price signals. The future value of this export energy is estimated using a separate forward-looking wholesale market model using a RIT-T-style methodology that considers the cost of the next-best generator that would be displaced by the exported energy in each time interval, taking into account South Australia's present and future generation mix.

- The positive yellow bars for options 2(a) and 2(b) show that these options also enable additional energy to be exported compared to the baseline option 1, because under these options export limits are only applied for a smaller proportion of the year (e.g. in the middle of a mild, sunny day when PV export is very high relative to underlying demand) to ensure network technical limits are respected.

- The negative blue bars for options 2(a) and 2(b) represent the total cost (CAPEX and OPEX) of the new operational systems required to enable dynamic export limits. The higher cost for option 2(b) reflects the higher cost of building a full LV network model under this option compared to the template-based model used in option 2(a).

- All figures are NPV to 2035

The figure shows that under the base case input assumptions the preferred option 2(a) has the highest net value (NPV to 2035) of all options considered. By managing DER exports largely within existing asset capacity, this option avoids the significant cost of network augmentation associated with option 3, while still enabling the majority of the market benefits from passive solar exports and active dispatch of VPPs. It outperforms option 2(b), which unlocks greater market benefits, but at much higher implementation cost.

7.2 Sensitivity Cases

The various sensitivity cases modelled are as follows:

#	Uptake scenario	VPP sensitivity
1	Neutral	45% VPP participation
2	PV strong	45% VPP participation
3	VPP strong	45% VPP participation
4	Weak uptake	45% VPP participation
5	Neutral	90% VPP participation
6	Neutral	10% VPP participation
7	VPP strong	90% VPP participation

In the following sections, we first consider the various uptake scenarios holding the VPP sensitivity constant (cases 1 – 4). This is followed by several sensitivities (cases 5 – 7) where different proportions of battery systems are participating in a centralised VPP orchestration scheme.

7.2.1 Varying uptake scenarios

Figure 20 shows the results comparing the potential LV management strategies against static limits under four different uptake scenarios.

It can be seen in each of the four scenarios presented, the use of the Dynamic Template approach delivers a positive cost-benefit result against the static limits approach, showing that this approach has merit irrespective of whether DER uptake rates are high or low. By contrast, the Fully Dynamic Model strategy only shows benefits in one of the four scenarios (VPP strong). In each of the other three it is shown to be less cost-efficient than the Static Limits approach.

The Add Capacity strategy, whereby the network is reinforced to permit customers to export in an unconstrained manner up to the 5kW per customer, is always shown to be a more expensive approach and never presents a net cost-benefit against static limits (nor against the Dynamic Template approach), due to its expense and underutilisation of network capacity.

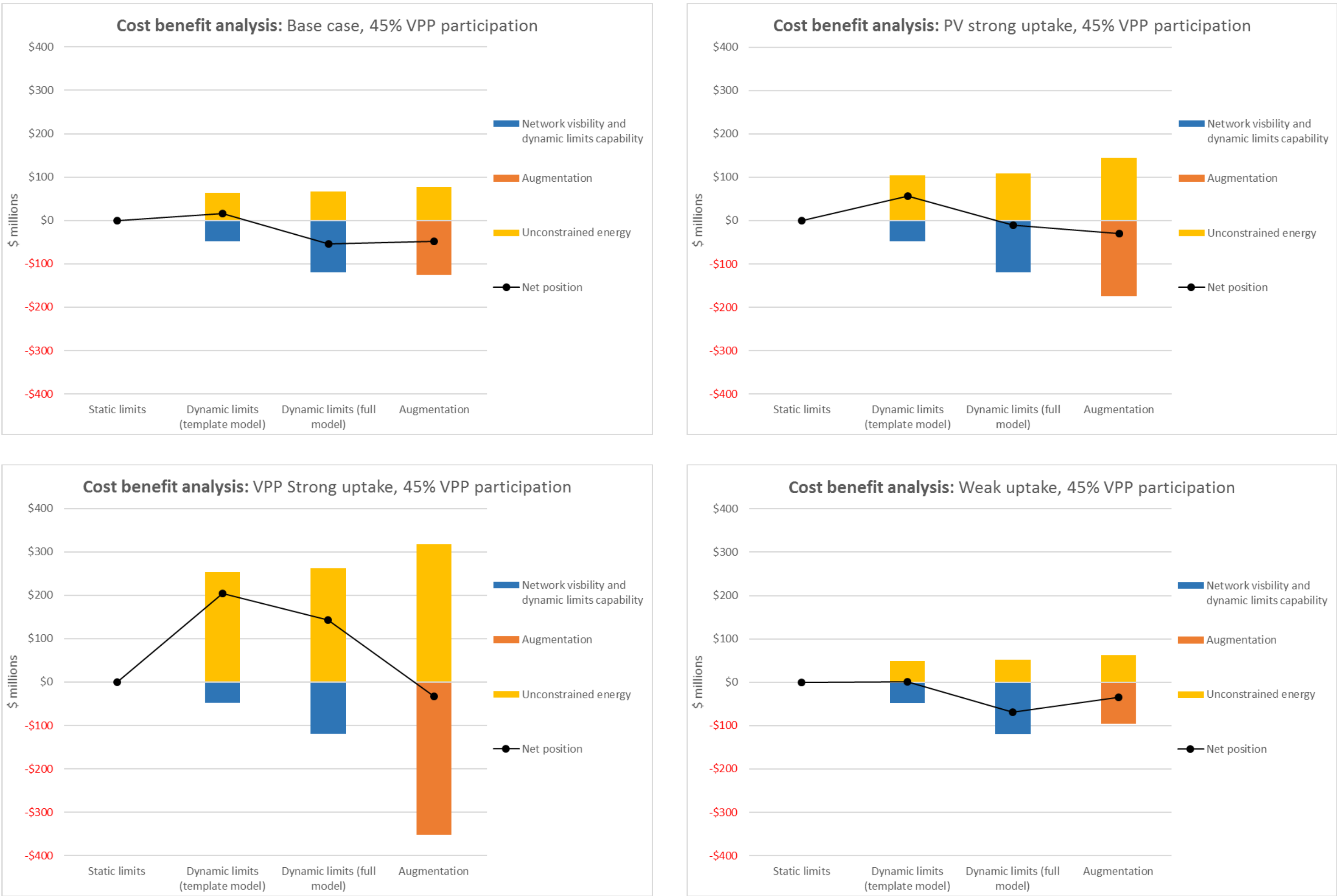

Figure 20 Cost benefit performance under various uptake scenarios

Detailed results are presented in Table 5. These results show that the Dynamic Template approach outperforms the Static Limits approach by between $1.2m and $205m across the four scenarios considered.

It should be noted that no costs are included for the systems that would be required to assess the hosting capacity of the network to determine when to reinforce under the augmentation strategy. This means that the relative cost gaps between dynamic templates and augmentation are likely to be bigger in reality than presented here as additional work would be necessary to identify (on a proactive or reactive basis) where the network augmentation was necessary. Similarly, it is likely that additional costs would be incurred managing the static limit investment option with primitive models and reactive management approaches to network performance issues.

Table 5 **Base case scenario investment performance (all $ figures are NPV 2020-2035)**

		Value of Unconstrained energy ($m)	Cost of Augmentation ($m)	Cost of DER network management platforms ($m)	Net position ($m)
Neutral	Dynamic template	$64.45	-	($47.87)	**$16.58**
	Dynamic full	$66.69	-	($119.98)	**($53.29)**
	Augmentation	$77.36	($125.98)	-	**($48.61)**
PV Strong	Dynamic template	$103.85	-	($47.87)	**$55.98**
	Dynamic full	$109.24	-	($119.98)	**($10.74)**
	Augmentation	$144.29	($174.11)	-	**($29.82)**
VPP Strong	Dynamic template	$252.49	-	($47.87)	**$204.62**
	Dynamic full	$262.88	-	($119.98)	**$142.9**
	Augmentation	$317.90	($351.42)	-	**($33.53)**
Weak Uptake	Dynamic template	$49.09	-	($47.87)	**$1.22**
	Dynamic full	$51.14	-	($119.98)	**($68.84)**
	Augmentation	$61.65	($95.71)	-	**($34.05)**

7.2.2 Sensitivities regarding VPP participation

This section reviews the results of the neutral (base case) and VPP uptake scenarios when the level of VPP participation varies (as per study cases 5 – 7).

The results of these sensitivity studies are shown in Figure 21 and summarised in Table 6.

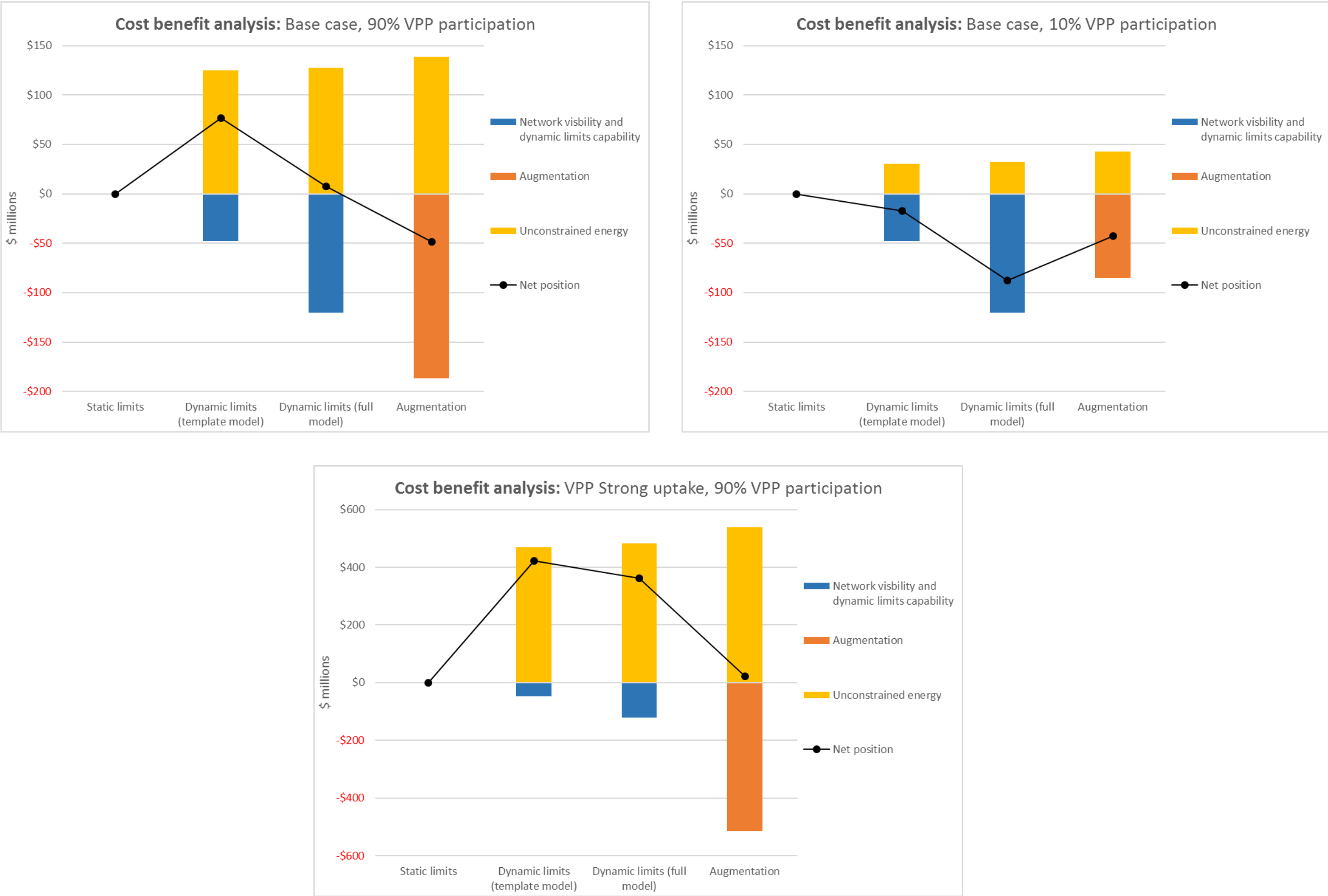

Figure 21 **Cost benefit performance under various VPP participation sensitivities**

Table 6 **Investment performance under VPP sensitivities (all $ figures are NPV 2020-2035)**

		Value of Unconstrained energy ($m)	Cost of Augmentation ($m)	Cost of DER network management platforms ($m)	Net position ($m)
Neutral Case 90% VPP Participation	Dynamic template	$124.63	-	($47.87)	**$76.75**
	Dynamic full	$127.41	-	($119.98)	**$7.42**
	Augmentation	$138.43	($187.08)	-	**($48.65)**
Neutral Case 10% VPP Participation	Dynamic template	$30.41	-	($47.87)	**($17.46)**
	Dynamic full	$32.33	-	($119.98)	**($87.65)**
	Augmentation	$42.50	($85.25)	-	**($42.75)**
VPP Strong 90% VPP Participation	Dynamic template	$469.53	-	($47.87)	**$421.66**
	Dynamic full	$482.44	-	($119.98)	**$362.46**
	Augmentation	$538.04	($515.45)	-	**$22.59**

The results indicate that in the sensitivities where VPP participation is higher, the Dynamic Templates strategy continues to be the most beneficial, generating a positive cost-benefit of between $77m - $422m. It is only in the sensitivity where VPP participation is much lower (10%) that the Dynamic Template strategy is outperformed by the Static Limits approach.

It is, however, worth noting that the extent to which it is outperformed is relatively low ($17m) in comparison to some of the benefits seen in the other cases examined. It should also be noted that it is still significantly more cost-efficient than the Fully Dynamic Model and the Augmentation approaches (outperforming these by $70m and $25m respectively).

7.3 Overview of investment performance

Section 7.2 above investigated the investment outcomes of selecting each of the strategic options in different growth scenarios. As already acknowledged within this report, exactly which of the scenarios studied is most likely to accurately describe the future is hard to state. This section, however, provides an overview of how each intervention performs when considering the potential range of growth scenarios.

Figure 22 shows an overview of the investment performance of each strategic choice, for each growth scenario, relative to the Static Limits approach.

It can be seen from Figure 22 that:

- There are strategic choices that can create better value for customers than the static limit approach to DER management.
- The most effective of these investments is the dynamic templates option, which would result in net benefits to customers in six out of the seven sensitivity cases studied against the counterfactual static limits position.
- Investing in Dynamic Templates is a lower risk for customers as it is only out-performed by Static Limits in one out of the seven sensitivity cases.
- Investing in the Add Capacity (network augmentation) strategy will result in a negative outcome for customers (relative to the Static Limit approach to managing DER) in six out of the seven sensitivity cases studied. It should also be remembered that this approach considered using the most economic network or non-network solution (including the use of tariff-based incentives) available to avoid the network issues in each instance.
- Adopting the Fully Dynamic Model approach results in a negative outcome for customers in five of the seven sensitivity cases studied. Again, in all cases, it is out-performed by the Dynamic Templates approach by a margin that is typically around $65m.

In summary, if the assumption was made that each of the growth scenarios studied has an equal chance of being the true representation of the future, then Figure 22 shows that the rational investment choice is the Dynamic Templates approach as not only does it minimise the potential loss of value to customers but it also maximises the value created (in comparison to the Static Limits approach) for customers.

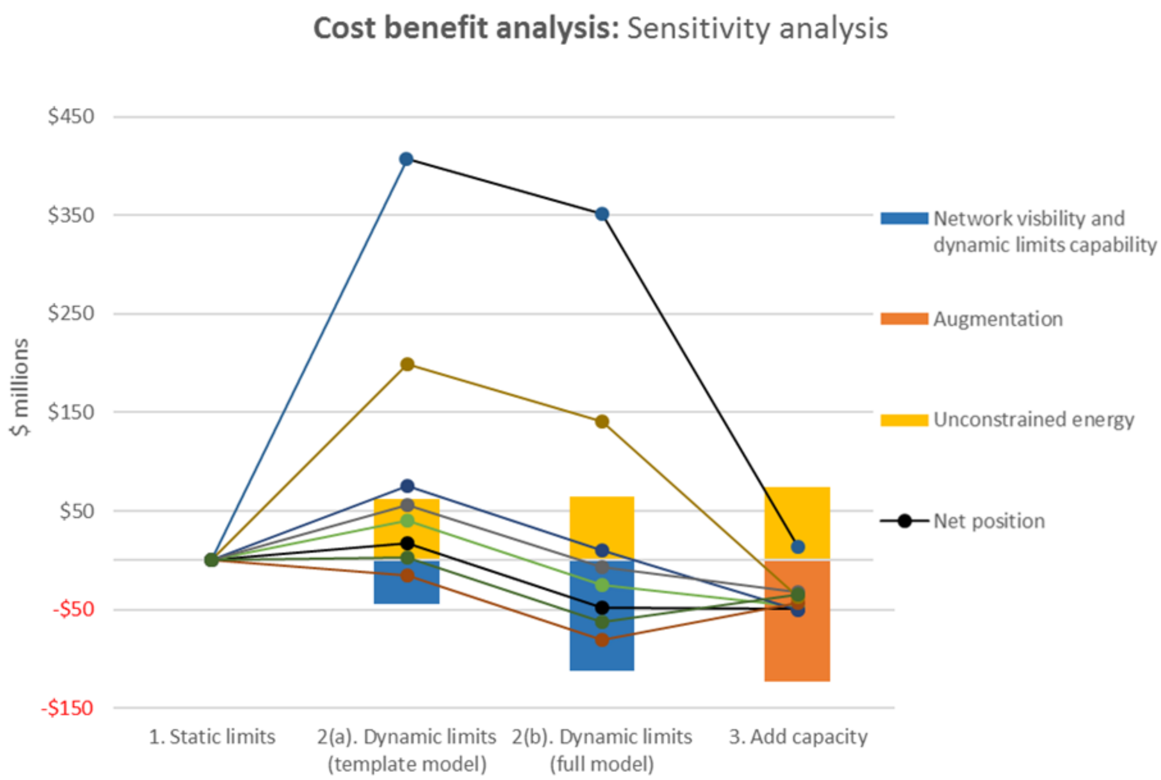

Figure 22 **The range of investment performance outcomes (relative to Static Limits)**

8. Discussion

8.1 Customer Proposition

Viewed from the customer perspective, each of the strategic options for management of the LV system will have different value propositions. These propositions are as follows:

- **Reduction of barriers to network access caused by capacity restrictions upon the low voltage network.** This proposition reflects the expectation of a DER owner to be able to export power into the LV network in acceptable time and quantity. This principle has already been explored from the economic perspective of all connectees in previous sections, but not from the perspective of a DER owner wishing to maximise their investment returns.
- **Facilitating DER participation in upstream distribution network management.** This proposition refers to an opportunity for customers who are connected at Low Voltage to help generate and share the value created by using DER to manage capacity limitations on the upstream distribution network.
- **Facilitating DER participation in upstream transmission network management.** This proposition refers to an opportunity for customers who are connected at Low Voltage to help generate and share the value created by using DER to manage capacity limitations on the upstream transmission network and to participate in the NEM by providing wholesale energy and ancillary services.

Table 7 provides an overview of how the LV management options contribute to the value propositions that can be made to customers. The two propositions relating to upstream network management present benefits to both DER owners, enabling them to access the full value stack on their DER investments, as well as non-DER owners where the cost to provide these services is less than the traditional, network side solution.

It is notable how both the dynamic strategies are the only two strategies that contribute to the two propositions that relate to upstream network management. They are able to do this because they establish information conduits that enable communication between LV connected DER and the network owner or operator domain.

It can be seen from Table 7 that the Static Limits strategy provides the worst customer proposition and from Figure 22 that across most of the growth scenarios, alternative LV management strategies perform better than the Static Limits strategy.

In comparison, review of Table 5 and Table 6 (in the previous chapter) and Table 7 shows that dynamic limits generally gives the best financial return, but also helps to offer all three of the customer propositions introduced herein.

Table 7 **Customer proposition associated with each LV management strategy**

LV management Strategic Option	Customer Proposition: Reduces network access barriers for DER caused from within the low Voltage network	Enables VPP market participation	Facilitates DER participation in upstream distribution network management (non-network solutions)	Facilitates DER participation in transmission network management (non-network solutions)
Static limits	✗	✗	✗	✗
Augmentation	✓	✓	✗	✗
Dynamic Templates	✓	✓	✓	✓[15]
Fully dynamic model	✓	✓	✓	✓

✗ - indicates that the strategy in no way contributes to the customer proposition

✓ indicates that the strategy contributes a capability towards fulfilling the customer proposition

8.2 Alternate views of the value of DER exports

Besides the values of DER accounted for there are further benefits that have not been quantified. DER can provide support for system frequency through FCAS and the competition brought about by increased supply of these services supports the delivery of these at least cost. Furthermore, DER contributes to the reduction of losses not only at the distribution level but also at transmission as the generation and consumption of energy are more closely co-located. Given that the DER typically being installed today either generates or stores renewable energy, enabling DER exports which displace fossil fuel generation brings reduced carbon emissions into the energy supply chain.

There are also potential social benefits to more customer DER assets in that they may be more engaged with the network service providers and their assets could help to provide security of supply to local areas.

8.3 Implications of employing the static network management approach

The overview in section 7.3 shows that there are alternatives to the static network limits strategy which provide a greater net value to electricity customers.

It is also observed that a Static Limits strategy would have significant implications upon SAPN's customers. The government of South Australia has a commitment to embark on a policy that will lead to the development of a 50,000-home virtual power plant[16]. The government expects that this

[15] It should be stressed that this report is not intended to imply that SAPN is developing IT systems for use within the Transmission network operations domain. But development of a capability for network operators to be able to communicate with LV connected DER would is a key step on the roadmap for use of LV DER within the transmission operations domain.

[16] https://virtualpowerplant.sa.gov.au/virtual-power-plant

programme is to have a significant effect on reducing the cost of electricity to customers. Adoption of the static limit investment approach would act as a barrier to VPP operations as each unit will have to operate beneath the appointed static limit at all times. This would effectively remove a significant portion of the value that is expected to be gathered by this investment because the VPP could not operate at its full potential. The cost of this lost opportunity to VPP investors has not been considered in this cost-benefit analysis which means that the costs of the static limit's strategy are understated.

Furthermore, setting static limits for DER is increasingly seen as an unacceptable solution to energy consumers, advocates and technology partners. AEMC say *"static export limits on export are a blunt approach to addressing the impact of distributed energy resources on the network… prohibiting new DER systems from exporting where local hosting capacity has been reached or imposing broad restrictions is unlikely to be efficient or to meet customer expectations."*

8.4 Implications of increasing network hosting capacity to support DER export

This analysis considered increasing network hosting capacity on a proactive basis to enable customers to continue to connect DER and export up to 5kW.

This was done by allowing the Transform Model® analysis to understand how many of SAPN's 75,500 LV feeders would fall outside of compliance across the DER growth scenarios considered. This analysis then calculated the least cost network or non-network solution to resolve the constraint and enable DER to continue to be connected. The model is "all-knowing" in that it has perfect visibility of when and where constraints bind which would not practically be true in lieu of investment in a network model. Hence the costs presented for this strategy in Section 7 are a lower bound on the investment required.

This Transform Model® analysis was able to choose from a pool of traditional network solutions such as new cables and transformers, smart grid solutions, as well as considering less traditional non-network solutions. This analysis also took account of DER led interventions such as Volt/VAr characteristics that are now commonly installed on DER systems.

Even with the possibility of using non-network alternatives such as demand response and smart inverters, the results summarised in section 7 demonstrated that the network augmentation strategy generally gave a poorer outcome for customers in comparison to either the use of static export limits or of dynamic management, indicating that this would be an inefficient approach to facilitating increased levels of DER in the network.

8.5 Implications of the dynamic model

The analysis considered the benefits of implementing the capabilities to generate and publish dynamic export limits in enabling the increased utilisation of network capacity for DER exports without investing in network upgrades.

The majority of the CAPEX and OPEX associated with this option is spent in the establishment of a platform for monitoring targeted areas of the LV network and modelling hosting capacity across the network. This capability will enable a range of other benefits not quantified in the analysis:

- It will enable all DER customers to participate in VPPs to provide energy to the wholesale market and help support the stability of the broader network through ancillary services.
- It will facilitate the publication of more accurate 'opportunity maps' of available network capacity, and facilitate better investment decisions by customers considering connecting embedded generators to the network

- It will enable more effective network planning and operations, including more proactive management of Quality of Supply (detecting and resolving potential issues before customers are impacted, which is not possible today)
- It will establish the commercial relationships and technical interfaces necessary to leverage network functions of third party smart meters. This has the potential to enable a range of other benefits beyond voltage monitoring such as outage detection and detection of neutral faults at customer premises, delivering on a key outcome intended by the Power of Choice reforms and the Competition in Metering rule change
- It will avoid the need for future capital expenditure on network-side monitoring by enabling access to the market for third-party data sources.
- It will provide the data necessary to identify opportunities for non-network solutions to network capacity constraints, and facilitate engagement with energy service providers for the broader range of non-network solutions that are beginning to emerge as new technology platforms enable aggregation of flexible loads such as hot water, pool pumps, air-conditioning and EV chargers.
- It will enable SAPN to leverage existing network infrastructure to deliver greater value (increase utilisation).
- By enabling greater access to available network capacity and avoiding unnecessary curtailment of ‘surplus’ solar energy via static export limits, the strategy will also:
    - Reduce CO2 emissions
    - Potentially enable customers to exceed current 5kW export limits at certain times, increasing the value of larger solar PV systems and, in particular, VPPs

Even without quantifying the additional benefits above, the Dynamic Templates model provides the greatest value to customers in 6 out of the 7 future scenarios considered in the sensitivity analysis.

9. Conclusions

This project has reviewed how SAPN can most efficiently manage their LV network in the future. This was done by adopting a process which:

- Considered a range of growth scenarios for the deployment of DER by LV connected customers
- Considered the challenges that SAPN would need to respond to in order to guarantee power quality for customers and maintain hosting capacity limits for each of the scenarios
- Developed several strategic options for how SAPN could manage their LV networks to maintain quality for customers.
- Conducted a cost-benefit analysis to show how each of the strategic options created or diminished value for SAPN’s customers across each of the DER growth scenarios. This cost-benefit analysis was limited to considering the expenditure required to ensure that the use of the LV network remained within available capacity against the value of network access to DER. This analysis did not consider the cost-benefit balance associated with upstream parts of the network.

The cost-benefit analysis showed that deploying a Static Limits strategy does not result in the best economic outcomes under 6 out of the 7 future growth scenarios considered in the sensitivity analysis. This process compared three alternative LV management strategies against the static limits approach; the Dynamic Templates, Full Dynamic Model and an Add Network Capacity approaches.

In six out of seven future growth scenarios it was shown that investing in a new operational platform to deliver the Dynamic Templates methodology gave better financial value to SAPN's customers than the static approach to managing DER. This value was significant and ranged between $1.2m to $421m depending on the growth scenario. In the lower growth scenarios, investing in the Dynamic Templates approach only performed worse than retaining the static management approach in one situation (a sensitivity case involving very low VPP participation rate, which seems unlikely given the direction of travel within South Australia).

A more advanced DER management strategy, known as the Fully Dynamic Model, was also tested which had higher resolution modelling functionality. Owing to the higher costs associated with establishing this strategy, it did not perform as strongly as the Dynamic Templates.

The use of a strategy to release additional hosting capacity via a range of infrastructure and non-network solutions was also explored. The cost-benefit model of the add capacity strategy made decisions to deploy an infrastructure or non-network solution in each case on the basis of a simulated economic choice that was "all-knowing" of the future growth. The augmentation approach was generally the most expensive of the strategies and was a worse proposition than the Static Limits approach in the majority of cases.

It is notable that this project has arrived at a set of conclusions which aligns with some of the key conclusions from the AEMC's recent report reviewing the regulatory framework[17] relating to electricity distribution networks in Australia. The particular points of the regulatory review that this report has replicated, using an independent analysis methodology, are as follows:

- Static network management strategies have limitations and are likely to create inefficiencies.
- A more dynamic approach to management of DER does create value for customers.

As a result of the analysis undertaken within the project, EA Technology recommends that pursuit of a static network management strategy does not promote value for SAPN's customers. Development of operational systems and capabilities that can dynamically manage DER to use the network in a manner that optimises the available network capacity will create greater value for SAPN's customers.

Therefore, allowing for the fact that there will be uncertainty with regard to which DER growth scenario is most likely to come to fruition, selection of the Dynamic Templates approach provides the least risk to customers and the greatest level of potential savings and is therefore recommended as SAPN's LV Management Strategy.

[17] https://www.aemc.gov.au/sites/default/files/2018-07/Final%20Report.pdf

Appendix I International Learnings

New Thames Valley Vision, SSEN -£30M ($54.9M) Trial - 2015-2016

	LV – Monitoring	Customer Info	LV – Modelling	LV – Orchestration
Demonstrations	250 End point monitors installed 100 Substations monitored Monitoring combined with clustering and buddying methodology to create leverage from sparse monitoring This was fed into the Customer info model	Using classification and aggregation methodology SSEN developed profiles of customer and DER behaviour to avoid having to conduct wide scale monitoring of customers	LV modelling was based on SSEN's geospatial records and combined with a load flow engine. Instead of using an assumed maximum demand per customer, the model applied a 30 minute resolution load profile for each customer Behaviour of individual feeders could be predicted when combined with the customer and DER load profiles created from monitoring	The project used an orchestration platform to control: Storage, response from buildings

Learnings

- Approximately 30% of this project cost was the establishment of the network modelling, monitoring and the orchestration platform
- The project learnt that efficiencies can be made by reducing the amount of monitoring that is pursued by correlating data to represent similar categories of customer. To ensure that profiles developed are within 99% accuracy, it was calculated that a coverage of around 60% of the population would have to be monitored,
- It is a very challenging task to actively recruit sufficient numbers of consumers to have their data sampled. The implication being that it isn't feasible to gather sufficient volumes of endpoint data and profiles if customers must opt-in. (Hence any strategy will have to depend on Smart DER or Smart meters)
- Consideration of monitoring costs implies that access to smart meter data may well prove to be the cheapest way to implement this methodology
- There can be significant challenges in overcoming lack of data on LV phasing and the location of where service connections are made onto mains cables.
- Manpower efficiencies can be made during new load/generation studies because of the availability of data rather than guesswork.
- Clear presentation of network stress points can create manpower efficiencies
- During network modelling, use of 30-minute customer & DER profiles instead of an ADMD approach created significant additional value through better use of the network
- This trial also provided statistics with regard to how robust data gathering from customer premises is likely to be. These statistics imply that any strategies reliant on GPRS communications should take account of the fact that there is an inherent level of unreliability and that any DER information gathering or orchestration approaches should allow for these effects.

Implementation towards business as usual

- The trial has demonstrated value streams discussed and not demonstrated any fatal flaws.
- The trial finished during the current pricing review. No comment can be made regarding what to what extent SSEN hope to investment in this technology in the forthcoming RIIO-ED2 price control.

Smart Urban Low Voltage Network,

UK Power Networks –£2.1M- ($3.1M) – 60 secondary substations and 140 LV link boxes - 2012-2015

	LV – Monitoring	Customer Info	LV – Modelling	LV – Orchestration
Demonstrations	This trial installed smart fuses and smart link technology into parts of the existing LV network. Not only could these smart devices instigate LV network switching, but they could also report back LV network loading from the LV substation and link pits along the feeder.			

Learnings

- This trial sought to investigate the possibility of automated LV networks to accelerate customer restoration following faults but also demonstrated a capability for LV network monitoring.
- This trial demonstrated a capability to gather feeder loading data and measure asymmetry at levels beneath the 400V bus bar without having to install telemetry in customers' homes and premises.
- This trial demonstrated that these smart devices can be combined with 3rd party LV network monitoring and LV network SCADA systems

General observations

- There is a growing trend for equipment manufacturers to offer smart LV devices that can also report back telemetry without the need additional SCADA equipment. In some cases, these devices also have local processing intelligence. These devices are being positioned to offer functions such as:
    - Local LV network automation or active management, which would lead to reduced supply disruption or reduced DER Curtailments
    - Detection of evolving LV cable faults, which would lead to reduced supply disruption
    - Local processing of measured data, which would lead to reduced quantities of data being transmitted and therefore lower operational costs.
- Use of this intelligence at a local level allows network operators to overcome reliability limitations of the local GPRS networks or make data transmission efficiencies because automation need not be impaired by communications Curtailments.
- These units also overcome operational issues. This is because, unlike Rogowski coils, they do not need to be removed from fuse carriages before operational staff can change fuses.

Future Network Modelling Functions

Electricity North West - £125k – ($228k) -2017

	LV – Monitoring	Customer Info	LV – Modelling	LV – Orchestration
Demonstrations			This project sought to set out the future requirement for modelling within ENWL across all voltage levels and what architecture this might need to use.	

Project opinions and findings

- This project believed even at LV, future modelling systems must deliver the following use cases:
    - **Near-Term Needs** – Ability to study LV new connections and calculation of load loss factors for tariff setting
    - **Medium Term Needs** – Customer connection self-service, Unbalanced network modelling, the capability to model the network using LCT and DER profiles, the capability to model the LV network using a time series.
- This project presented the view that value can be created in the modelling process by ensuring that data handling by users should be fully automated to increasing productivity and reducing human error.

This project presented that the view that a topological model is useful for some parts of a network business, but to achieve the use cases already listed on this slide, load flow capability is essential

Customer-Led Network Revolution, Northern Powergrid

This was a £31M ($56M) Trial that ran until 2015. This trial encompassed across 11000 domestic customers and 2000 SME and Generation customers

	LV – Monitoring	Customer Info	LV – Modelling	LV – Orchestration
Demonstrations	This trial implemented monitoring in defined trial areas from the top of the network all the way down to the very end of LV feeders. This data was used to informed the state estimation model which looked at the near future performance of the distribution network	The trail sought to utilise smart devices within the customers preemies This trial made some strong conclusions about the maturity of the supply chain for smart home devices and the ability to recover data or send instructions to customers premises.	This trial reviewed modelling approach's from the top of the network all the way to LV using real time modelling and an optimisation engine. This state estimation modelled the network under existing and next fault conditions. Developed NPADDS (Network planning and design decision tool) based on	This trial employed an Active Network Management (ANM) platform that controlled load and generation, across a wide area at all voltages to ensure that suitable network quality was delivered. This trial also had an initial ambition to had an ambition to investigate PV within premises balancing, which had to be revised due to the relative maturity of the supply chain

Learnings

- Regular domestic customers contributed to peak demand much less than originally expected
- Impact of Solar PV is lessened due to diversity in panel alignment, demonstrated that a 10% reduction in peak demand can be justified
- Demonstrated that value can be obtained by starting with simple forms of localised ANM to solve local issues, with complicated ANM schemes only justified in networks with multiple congestion stacks
- Time of use tariffs were an effective means to get domestic customers to change their data
- It was very difficult to get SME or I&C business customers involved as the trial was a distraction from their normal business
- It was very difficult to recruit domestic active consumers.
- It was found that even though real-time network modelling was a well-proven technology at Transmission levels in the UK, the complexity of even the limited sections of distribution network within the trial means that the model developed was even more complex than that for the entire GB transmission system.
- Despite the complexity, some of the benefits of the real-time state estimation across the entire trial area were:
    - Ability to optimise voltage set points across active voltage control devices
    - Ability to a trade-off between network goals and Curtailments, e.g. lowering network voltage
- The close down of this trial firmly states that being able to model the network issue that is being considered and being able to monitor the issue to validate the conclusions is fundamental to being able to economically remove network voltage Curtailments
- The ability to dynamically adjust voltage or reactive power settings of active devices (generation and tap changers), employing bespoke voltage setting or even simply increasing voltage control range creates value in comparison to constraining generation to avoid network voltage issues.
- This project offers some significant learning points with regards to network operators interfacing with smart devices within domestic properties as a means for network balancing and gathering data:

- Initially, this project had an aim to procure smart devices to be placed within domestic properties that could be automatically scheduled to soak up production from PV panels. It was found at the time of this project that the supply chain for smart devices that could be stopped and started in response to network issues was weak. To some extent, this issue will be overcome when domestic storage matures

- Significant issues should be expected when seeking to gather data from within customers houses, issues that were encountered were:

  - Many premises still do not have access to broadband or even a telephone landline

  - There are significant data compatibility issues between devices and manufacturers

  - Even where customers do have a broadband connection, there will still be data communications issues

  - Arranging times for domestic installation of data handling equipment such as modems or smart meters can be a significant barrier achieving project aims. This effect is further compounded if any modifications must be made to household wiring to enable secondary monitoring equipment

  - Data compatibility issues between industry partners should be expected and significant effort should be expected to manipulate the data into a state that is fit for use by the network operator.

- A recommendation made by this project is that a possible mitigation to the issues encountered would be the establishment of a data team within a networks company, whose role would be to ensure that end-to-end integrity and compatibility of data flows is to an acceptable standard.

Heerhugowaard Trial– Aliander

	LV – Monitoring	Customer Info	LV – Modelling	LV – Orchestration
Demonstrations	Because USEF is a trading/orchestration platform, it is not focused on monitoring.	This protocol implicitly assumes that all participating consumers are happy to share meter data and offer the import/export flexibility of their smart devices and therefore offer the data that facilitates this. There is no publically available information with regard to how robust the experience of data communications to and from customers premises has been.	This protocol does not undertake network modelling but is dependant on the network operator informing the protocol of the capacity at "pinch points"	This framework allows the DSO to indirectly place limits on the maximum import or export of customers within a geographic boundary. This framework also allows the DSO to "turn up" or "turn down" services from DER or customers to avoid network issues. This framework assumes that the end consumer has opted into allow their smart devices (Storage, EV's, heating, cooling etc) be controlled by the platform.

This is a 200-house flexibility trial, which seeks to use the availability of flexible energy resources within these houses to manage the local electricity network.

This trial is the largest to date demonstration of the Universal Smart Energy Framework (USEF) https://www.usef.energy/. USEF is a set of protocols that can be implemented to enable consumers to sell their capability to vary their import and export power.

The network is safeguarded by a set of protocols where the network operator can specify the maximum bi-directional power transfer acceptable across a network pinch point, even at LV. The protocol then ensures that all transactions do not exceed these limits.

Opportunities are created for the network operator to purchase these services to avoid LV network issues, or even avoid issues higher up the network. The USEF protocol assumes that all customer flexibility is commercially enabled by an Aggregator

This framework has a protocol layer which is designed to allow participation in the market via the customers own domestic telecommunications connection. This protocol layer includes cybersecurity and customer data security protection. As a further countermeasure, this layer also offers an "anti-gaming" feature to prohibit abuse of the market.

This protocol is dependent on each consumer sharing data from their house about energy consumption and "smart devices"

In addition to this Aliander trial, SP Energy networks in the UK have announced that they will be trialling the USEF protocol on their network under the $9.1M trial known as Project Fusion. (10% of the Project Fusion cost is equipment, 50% of this cost is implementing and commissioning the platform)

CPUC Smart Inverter Standards, Regulatory Change – Rule 21

	LV – Monitoring	Customer Info	LV – Modelling	LV – Orchestration
Demonstrations	.	Work is underway to mandate capability for DER to report back data, including voltage, P & Q, rating and meter number		Work is underway to mandate control capability for DER to be turned on and off or ramped Work is underway to mandate scheduling capability for DER

The three utilities within the CPUC jurisdiction have now recommended changes to their generation connection methodology known as rule 21 as summarised above. At the domestic level, this rule is being implemented in three phases, where:

Phase 1 was enacted from 9/9/17 and requires all inverters to meet UL 1741 standard, which mainly focuses on riding through a wider voltage and frequency band than previous.

Phase 2 considers communications protocols for data exchange between inverters and utilities

Phase 3 considers the implementation of data exchange between inverters and utilities

Only phase 1 has an implementation date and it is understood that testing for phase 2 capability is presently underway. Phase 2 recommendations can be found here: http://www.energy.ca.gov/electricity_analysis/rule21/documents/SIWG_Phase_2_Communications_Recommendations_for_CPUC.pdf

Phase 3 initial capability requirements are fully discussed here:
http://www.energy.ca.gov/electricity_analysis/rule21/documents/phase3/SIWG_Phase_3_Working_Document_March_31_2017.pdf

The most recent status of phase 2 and phase 3 is shown here:

http://docs.cpuc.ca.gov/PublishedDocs/Published/G000/M212/K198/212198679.PDF

There has been a significant contraction of ambition and a slippage of delivery dates during this project.

The findings from NTVV and Customer-Led network revolution regarding data communications with domestic homes make an interesting counterpoint to the intention to gather DER information from homes.

The present ambition for phase 3 is for smart inverters to monitor the following data:

a Smart Inverter production or consumption of active power (watts).

b. Smart Inverter consumption or production of reactive power (vars)

c. Phase currents measure at the AC terminal of the Smart Inverter (amps)

d. Phase measured at the AC terminals of the Smart Inverter (volts)

e. Frequency measured at the AC terminals of the Smart Inverter (Hz)

f. The operational energy of storage systems

Ambitions remain within this jurisdiction to be able to:

- limit or to schedule power output from inverters.

- Administer reconnection functions after a power cut
- Enact frequency/watt mode
- Enact volt/var mode

It appears that the delivery date is unlikely to be before December 2019 and is still dependant on approvals of IEEE 1547.1 protocol and certification of the protocol by Sunspec alliance.

Appendix II Network Templates

Network Templates was a trial introduced by Western Power Distribution in the UK. The purpose of this trial was to develop a methodology which allowed a network operator to have a methodology to assess the remaining capacity upon LV feeders without the need to undertake ubiquitous monitoring or construction of a bespoke model for each LV feeder.

The process for the Templates methodology is as follows:

1. The starting point for this methodology was to install a large number of substation monitors and end-point monitors to record voltage at the extremities. These readings were used to build up a statistically valid insight into the peak flow, peak voltage and loading patterns across a sample population of feeders.

   To put the sample size into perspective, WPD Wales have 1.19m customers and 40,111 transformers and the sampling process installed monitors to gather readings at 824 transformers and monitored the voltage at 3,600 LV feeder endpoints. All monitored data was uploaded to servers for analysis.

   The sample selection sought to capture a wide variety of homes in South Wales with an emphasis on including homes with roof-mounted PV.

2. Following an extensive sense checking exercise to flag monitoring errors, a clustering process is applied to the measured patterns for each substation. The purpose of the clustering process is to define clusters of substations within which the measured patterns are most similar. Rather than being a subjective process, this part of the methodology used algorithms known as the "K Means" approach and the "Agglomerative Hierarchical Method". WPD's trial suggested that 10 Clusters was the correct number for their network and it was also shown to be effective on other UK DNO networks.
   .
3. An innovative feature of the WPD project was that the loading patterns were clustered on the basis of a normalised loading pattern rather than in absolute kW. A similar process was conducted that linked voltage measurements at remote feeder ends on a per phase basis associated with substations in each of the different clusters and calculating the average voltage profiles for each cluster. This meant that it would be possible to take the underlying stress patterns that were applicable to members of each cluster than then scale them up on the basis of fixed data that was known about a particular feeder.

4. To take advantage of the normalised load curves in 3, a process was developed to predict which cluster any LV feeder might belong to on the basis of fixed and known data. By entering the parameters into the cluster model, the model was able to inform the user of the statistically most likely cluster that would represent a particular feeder. The parameters used to predict cluster membership in this trial were:
   - Number of customers adhering to a fixed settlement profile upon a feeder
   - Source transformer type and size
   - Percentage penetration of Industrial and Commercial customers
   - Percentage of Half Hourly metered customers along the feeder (for the avoidance of confusion, the actual half hourly consumption data was not required, just their metering methodology)
   - The total length of HV source feeder
   - Number of LV feeders fed from the substation
   - Percentage of OH line (at HV feeder)

   This part of the model would then allow a normalised loading pattern to be assigned to the feeder of interest. In the WPD trial, the normalised loading pattern describe characteristic days across different seasons (i.e. Weekday/Saturday/Sunday in Spring, Summer, Autumn and Winter).

It should be noted that the LV Templates trial placed a particular focus on the network stresses attributed to Low Carbon domestic generation and how to sample feeders to obtain a representative expression of low carbon technology behaviour. It is noted that a possible limitation of this methodology was that it took place before the widespread availability of domestic battery storage systems.

This part of the workstream leads to some significant conclusions including that the observed export from roof-mounted PV systems was 80% of the expected levels. This was due to intricacies within the PV module rating systems. The trial also showed the effect of domestic export variance due to PV module tilt angle and compass orientation. This trial also demonstrated that an accurate indication of aggregate PV output can be obtained by monitoring a single “proxy” installation within a postcode locality and factoring this up.

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