On the calculation and use of dynamic operating envelopes

evolve Project M4 Knowledge Sharing Report

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CRICOS Provider No. 00120C

Acknowledgement: *This Project received funding from ARENA as part of ARENA's Advancing Renewables Program and from the NSW Government.*

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1. Glossary

Term	Definition
Active Network Management	The operational systems and processes by which DER can be actively controlled to prevent breaching physical or operational limits.
Aggregation Zone	The region of a network within which operating envelopes can be aggregated.
Connection Point	The network location where a customer is electrically connected into the electricity system.
DER	Distributed Energy Resources, or ‘DER’, are smaller– scale devices that can either use, generate or store electricity, and form a part of the local distribution system, serving homes and businesses. DER can include renewable generation such as rooftop solar photovoltaic (PV) systems, energy storage, electric vehicles (EVs), and technology to manage demand at a premises.[1]
DNSP	Distribution Network Service Provider, the organisations responsible for managing and operating electricity distribution networks.
Hosting Capacity	The real and reactive power contributions from DER that can be imported or exported into the electricity grid without breaching the physical or operational limits of the electricity distribution network.
NMI	National Metering Identifier (NMI) is a unique 10 or 11 digit number used to identify every electricity network connection point in Australia.
(Dynamic) Operating Envelope	A dynamic operating envelope is a principled allocation of the available hosting capacity to individual or aggregate DER or connection points within a segment of an electricity distribution network in each time interval (usually 5 or 30 minutes). In this report, we will use dynamic operating envelope and operating envelope interchangeably.

[1] https://www.wa.gov.au/sites/default/files/2020-04/DER_Roadmap.pdf

2. Executive Summary

We are currently witnessing the increasing deployment of DER including distributed solar PV, residential and suburb scale battery storage, electric vehicles and controllable loads. Overwhelmingly, these DER resources are being installed in the low and medium voltage segments of electricity distribution networks. These DER assets can contribute to energy reliability and energy security through their participation in markets for energy and ancillary services. However, without appropriate co-ordination DER can in result in dynamic two-way flows of energy that threaten the physical or operational limits of electricity distribution networks.

In this context, there are open questions about what new technology capabilities, regulations and market mechanisms are necessary to support the integration of DER without breaching the physical and operational limits of distribution networks. In the evolve Project, we are exploring the use of dynamic operating envelopes to address this question.

What is an operating envelope?

An operating envelope is the DER or connection point behaviour that can be accommodated before physical or operational limits of a distribution network are breached. A dynamic operating envelope is a principled allocation of the available hosting capacity to individual or aggregate DER or connection points within a segment of an electricity distribution network in each time interval. A dynamic operating envelope essentially provides upper and lower bounds on the import or export power in a given time interval for either individual DER assets or a connection point.

How are operating envelopes calculated?

The high-level approach for the calculation of a dynamic operating envelope in each time interval is described in Figure 1 below.

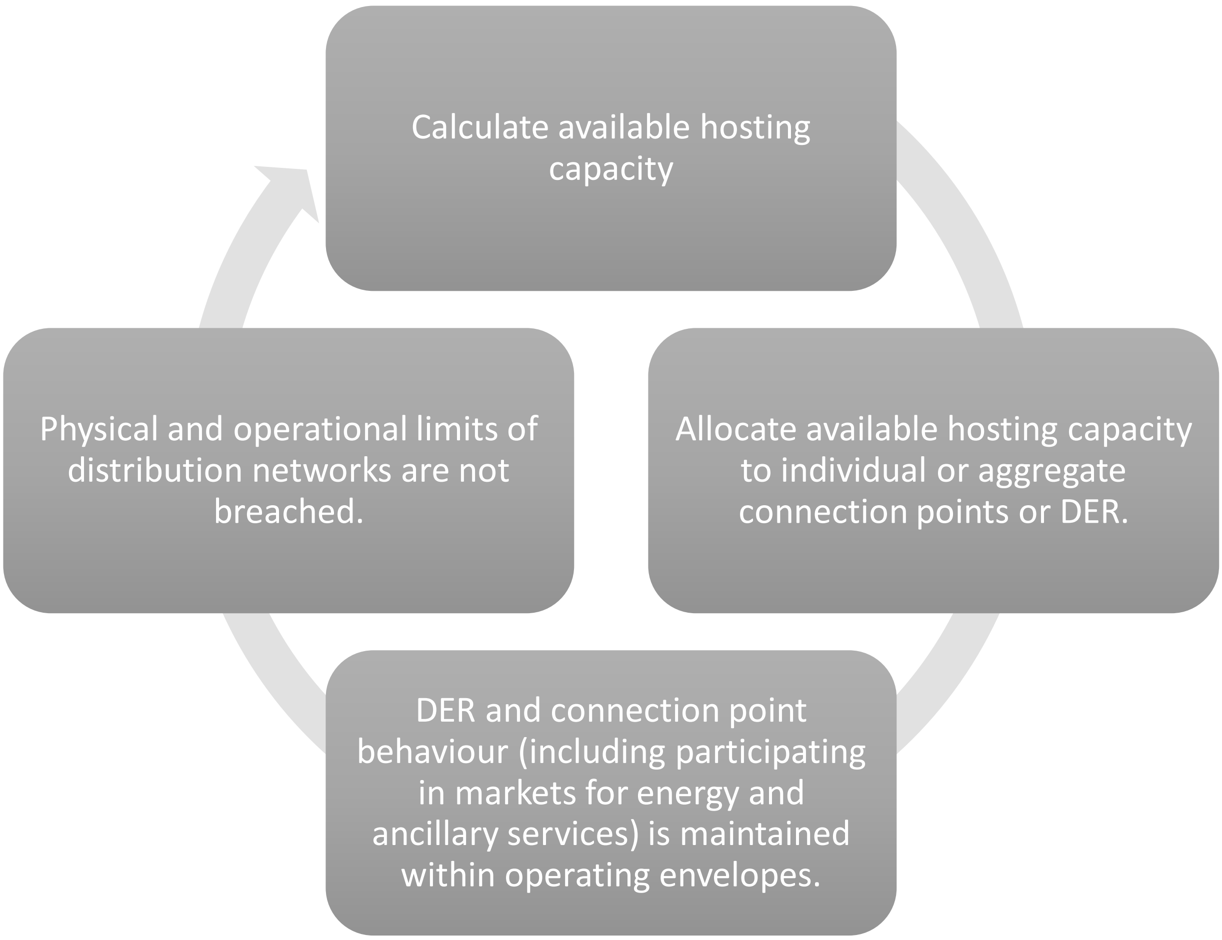

Figure 1. The lifecycle of an operating envelope in each time interval.

Operating envelope benefits

There are several benefits of operating envelopes at the current maturity levels of DER deployed within the electricity system:

1) Operating envelopes can address multiple use cases including challenges currently being faced in both electricity distribution networks and at the whole of system level.
2) Operating envelopes promise to be simple to implement across a variety of different DER assets, and do not require the use of sophisticated local control and optimisation systems. This has the potential to increase adoption and compliance from the variety of DER assets installed in Australian distribution networks.
3) Operating envelopes can be deployed progressively into different segments of a distribution network as they are needed.

Implementation

Operating envelopes are being implemented within the evolve framework, an open-source technology framework (Figure 2) which is deployed into cloud infrastructure and integrated with both DNSP and aggregator systems. The evolve framework ingests the relevant network and DER data and then makes this available for analysis in a standards based form. The calculation and publication of operating envelopes are implemented as a series of software modules and algorithms within the evolve framework.

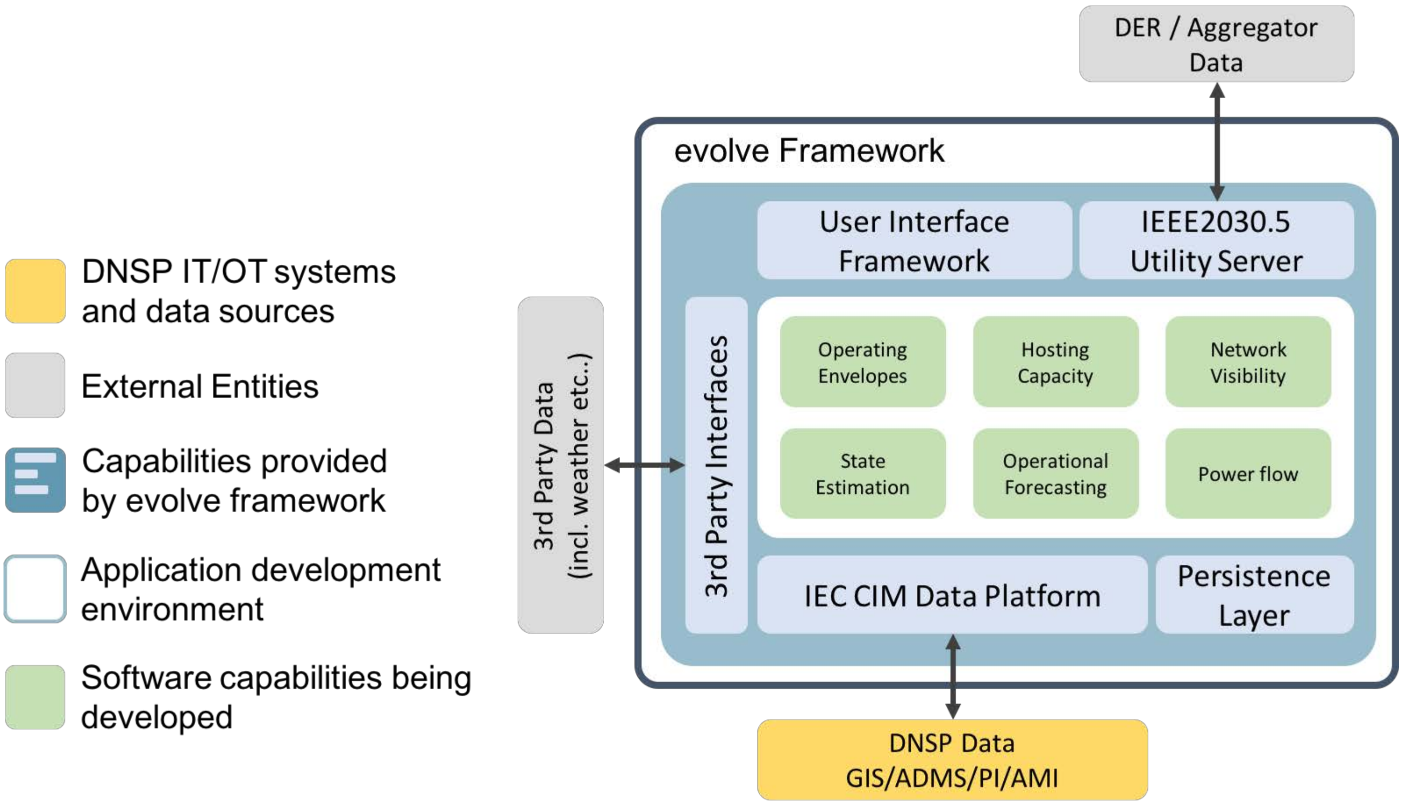

Figure 2. The evolve framework inside which dynamic operating envelopes are being developed and deployed.

This report is a review of operating envelopes and the methods used in their calculation, and is delivered as one of the knowledge sharing requirements of the evolve Project. This is the first iteration of this report and will be updated as the evolve project progresses, with the final report released in March 2022.

3. Introduction

Distributed Energy Resources (DER)

The uptake of Distributed Energy Resources (DER) represents a transformational change to the energy mix, structure and operation of power systems and markets. Overwhelmingly, these DER resources are being installed in the low and medium voltage segments of electricity distribution networks globally.

> *"Distributed Energy Resources, or 'DER', are smaller– scale devices that can either use, generate or store electricity, and form a part of the local distribution system, serving homes and businesses. DER can include renewable generation such as rooftop solar photovoltaic (PV) systems, energy storage, electric vehicles (EVs), and technology to manage demand at a premises".*[2]

As DER adoption increases, global electricity systems will demonstrate increasing levels of decentralisation, with this change currently occurring faster in Australia than any other nation (Figure 3).

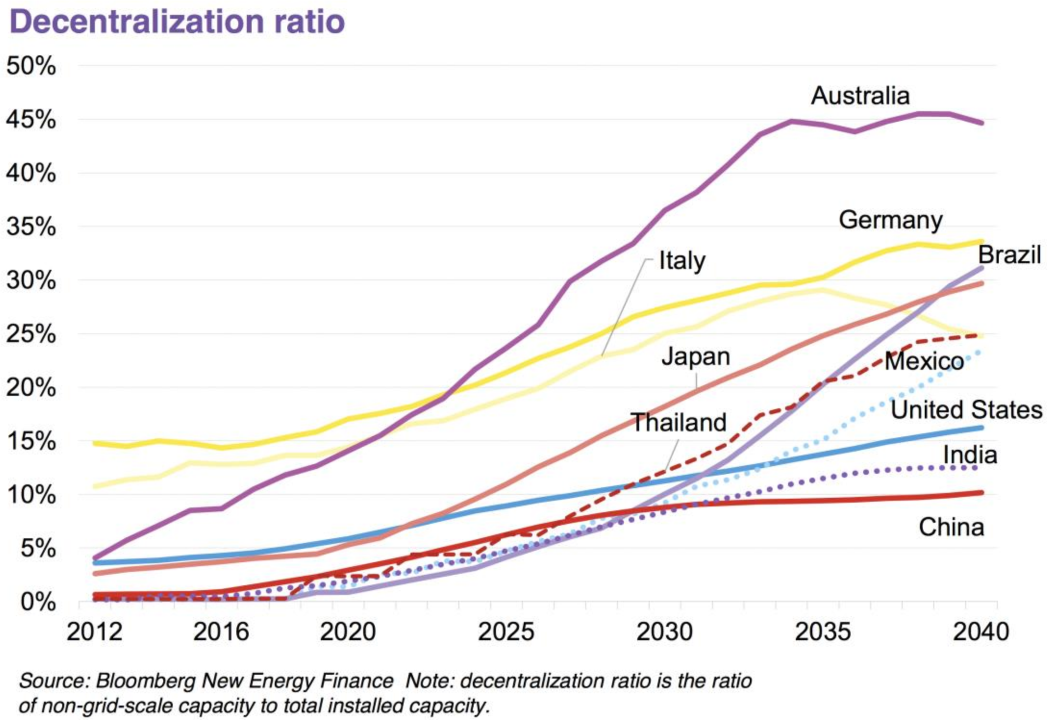

Figure 3. Many grids globally will demonstrate increasingly high levels of decentralisation over the decades ahead (Bloomberg New Energy Finance - New Energy Outlook 2017).

The AEMO 2020 Integrated System Plan (ISP)[3] notes that distributed energy resources are expected to double or even triple by 2040 and could provide up to 13% to 22% of total underlying annual NEM energy consumption by 2050. Driving the growth of DER in Australia will be the continued high uptake of distributed solar PV (Figure 4) through to 2050 and likely beyond.

The ISP also forecasts growth in behind the meter (BTM) residential battery storage. It is as yet unknown what percentage of BTM batteries will be orchestrated through participation in virtual power plants (VPPs) or if they will be predominantly installed by customers with solar PV to maximise solar self-consumption.

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[2] https://www.wa.gov.au/sites/default/files/2020-04/DER_Roadmap.pdf

[3] https://aemo.com.au/en/energy-systems/major-publications/integrated-system-plan-isp/2020-integrated-system-plan-isp

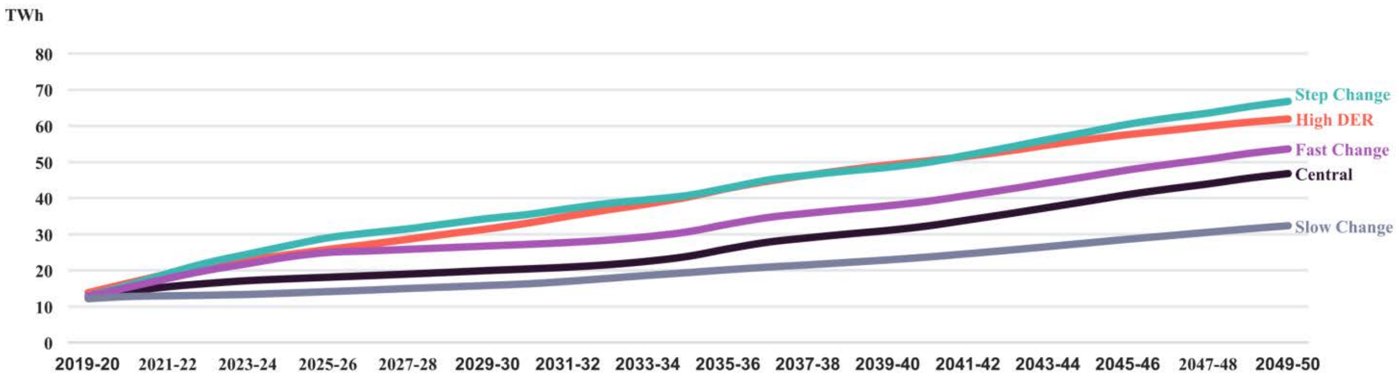


Figure 4. Distributed PV generation to 2050 (AEMO ISP 2020)

Battery storage connected within distribution networks is also likely to grow over the long term due to emerging opportunities for community and suburb scale batteries which offer benefits for customers who cannot access residential batteries. Community or suburb scale batteries will service customer desires for battery storage for those who cannot afford residential batteries, as well as those renting or who live in apartments, for whom it is often impossible to install batteries within their premises. While it is impossible to predict the uptake of community batteries, appropriate regulatory settings could result in a large fraction of the forecast utility battery uptake being community battery assets of less than 5MW[4].

From the mid-2020s onwards, there is also an expectation of greater electric vehicle (EV) adoption (Figure 5) which under the Step Change scenario modelled in the AEMO 2020 ISP would mean that:

"EVs account for 12% of underlying 'power point' NEM consumption by 2040"

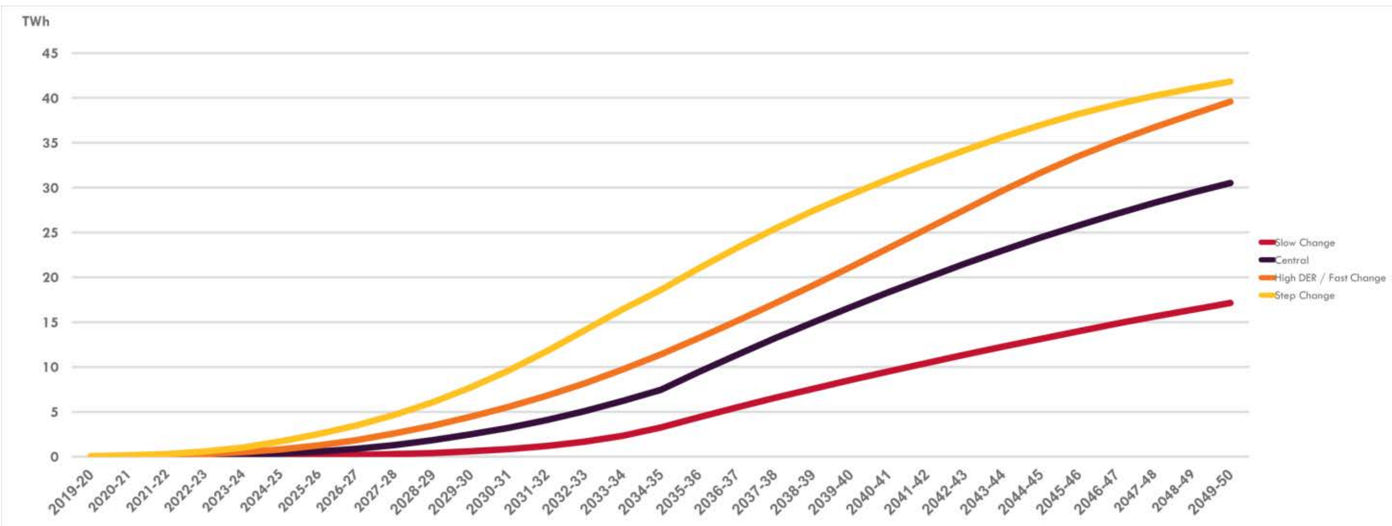


Figure 5. EV electricity consumption to 2050 (AEMO ESOO 2019[5])

While these DER assets will contribute to both increasing generation and demand, there is likely to be a significant time mismatch between the periods of peak DER import and export behaviour in the distribution network. While distributed solar generation tends to peak in the middle of the day, EV charging is likely to occur in the early to mid-evening. There is potential for battery storage to help balance this mismatch, however, as a dispatchable resource, battery storage will also contribute to energy reliability and energy

[4] https://arena.gov.au/projects/community-models-for-deploying-and-operating-distributed-energy-resources/

[5] https://aemo.com.au/en/energy-systems/electricity/national-electricity-market-nem/nem-forecasting-and-planning/forecasting-and-reliability/nem-electricity-statement-of-opportunities-esoo

security through participation in markets for energy and ancillary services. Collectively, these considerations mean that the significant uptake of un-orchestrated DER will result in dynamic two-ways flows of energy within electricity distribution networks.

Electricity Distribution Networks

Electricity distribution networks provide the electrical connection from customers to the overall electricity grid (see Figure 6), allowing bi-directional flows of energy between the customer and the system. For this reason, electricity distribution networks are said to provide the "last mile" of connectivity. In Australia, electricity distribution networks span almost 900,000km[6].

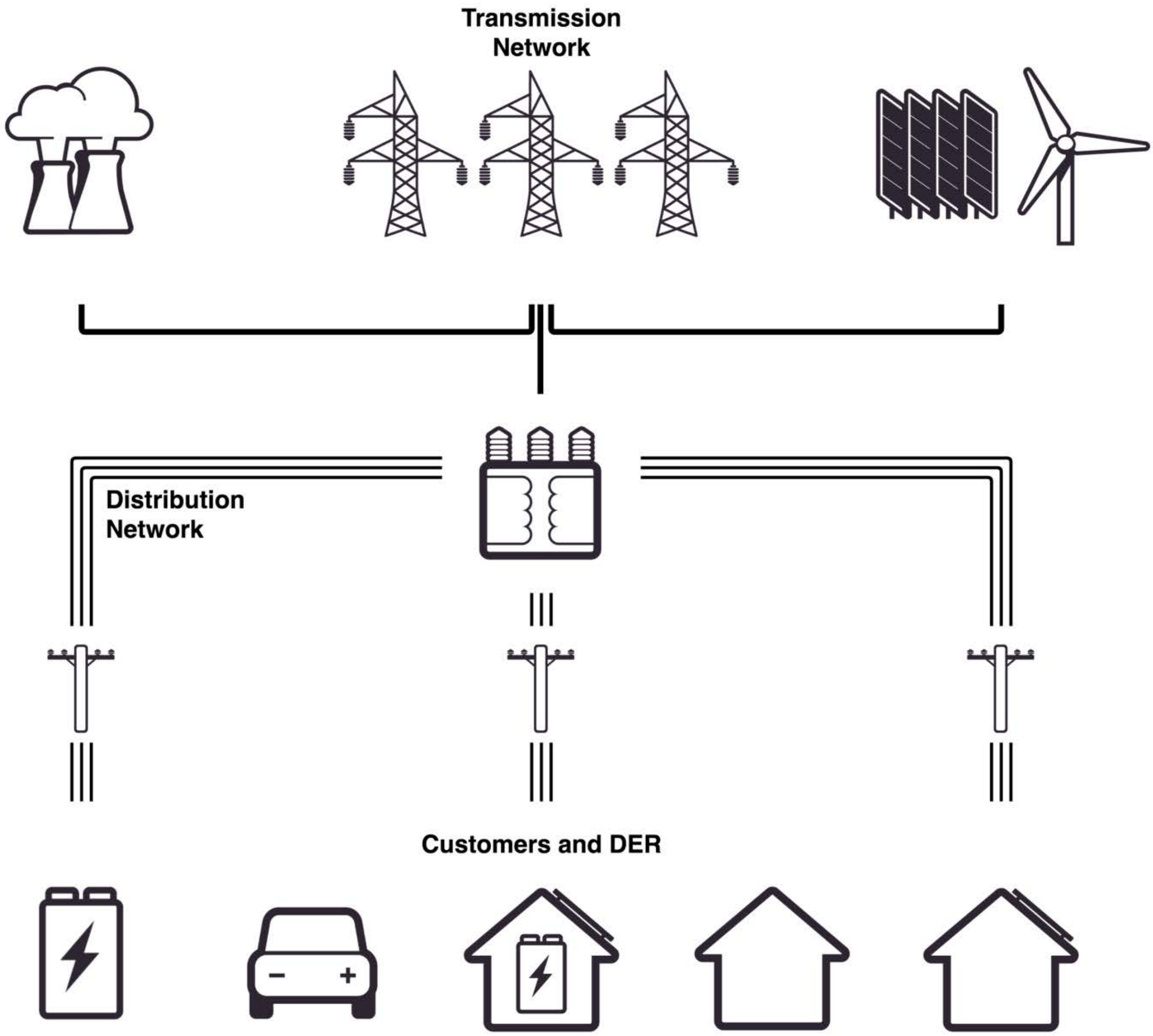


Figure 6. In Australia, DER assets are overwhelmingly installed in the low (415V) and medium (11kV) voltage regions of electricity distribution networks.

Prior to the uptake of DER, distribution networks typically experienced one-way aggregate energy flows that were predictable. The networks were designed such that they would remain within their physical and operational limits for these well characterised energy consumption patterns. In contrast, electricity distribution networks with a high uptake of DER will experience dynamic two-way flows of energy. As DER assets also begin to routinely participate in markets for energy and ancillary services, their behaviour may threaten the physical or operational limits of distribution networks.

[6] https://www.energynetworks.com.au/resources/fact-sheets/guide-to-australias-energy-networks/

Under their operating licenses, the distribution network service providers (DNSPs) who operate electricity distribution networks must ensure their electricity distribution networks maintain certain “quality of supply” outcomes such as operating within certain voltage ranges at consumer connection points. The networks must also maintain high levels of reliability and availability, and are heavily penalised for breaches. In practice this means ensuring that distribution networks are operated within both voltage and thermal limits, something that is discussed in greater detail in the following section. It is worth noting that in some locations high uptake DER, particularly solar PV, are already breaching physical and operational limits (Figure 7).

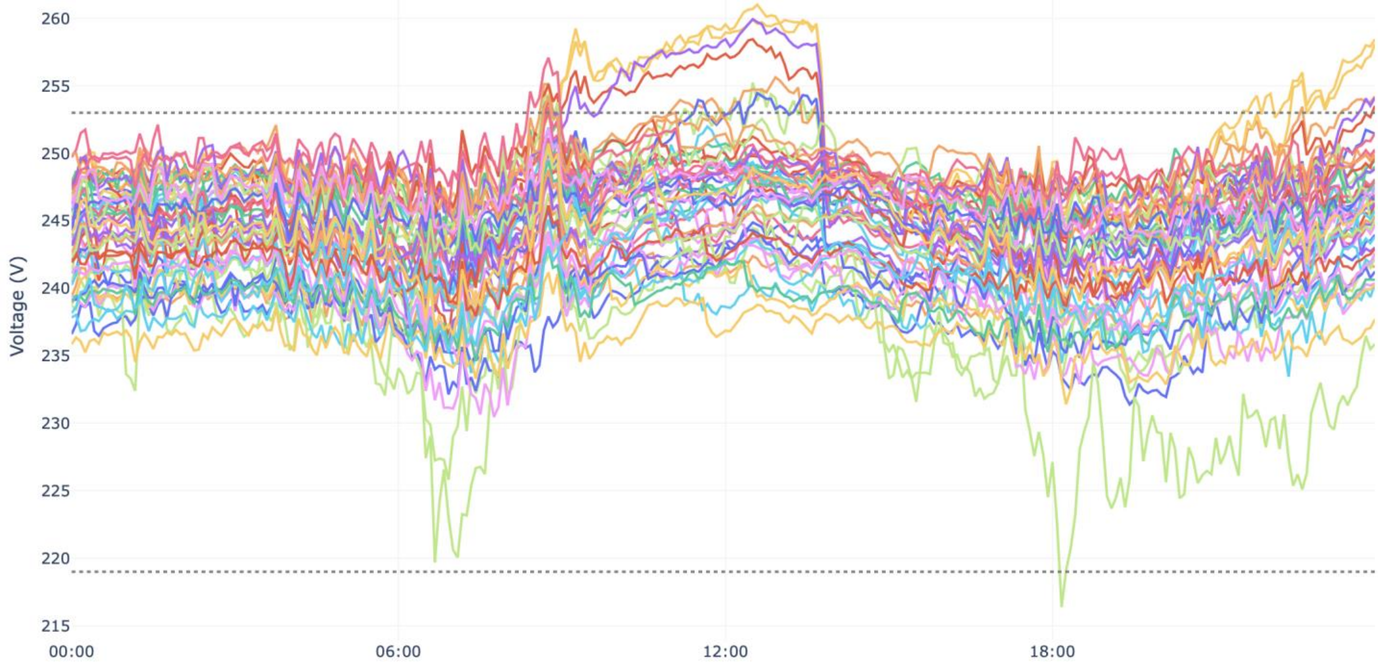


Figure 7. Voltage measurements from customers participating in the ACT NextGen Battery Storage Program for the 30th August 2018. These measurements demonstrate over-voltage conditions during the day due to residential solar PV, with some under-voltage conditions occurring in the morning and evening peak periods due to high-demand. This image is a clear example of the increasing dynamic range of voltage conditions experienced on the electricity distribution network.

With the significant forecast uptake of DER, and an awareness of the challenges being faced by electricity distribution networks, there are open questions about what new technology capabilities, regulations and market mechanisms are necessary to support the integration of DER without breaching the physical and operational limits of distribution networks.

Within the evolve project, we are addressing this question through the development of dynamic operating envelopes. To present a comprehensive overview of dynamic operating envelopes, the following sections cover respectively:

- how we model and analyse the behaviour of electricity distribution networks;
- what dynamic operating envelopes are and are not;
- how dynamic operating envelopes are calculated;
- the benefits of dynamic operating envelopes; and
- how we have implemented dynamic operating envelopes in the evolve project.

This is the first iteration of this report and will be updated as the evolve project progresses, with the final report released in March 2022.

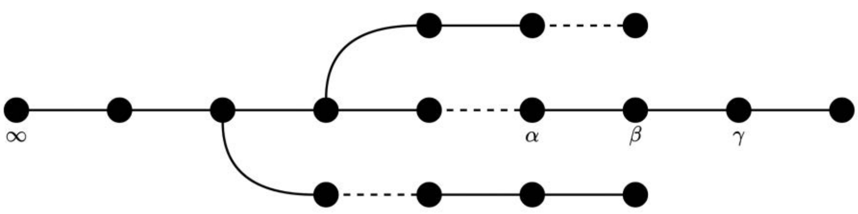
4. Modelling and Analysing Electricity Distribution Networks

Modelling Electricity Distribution Networks

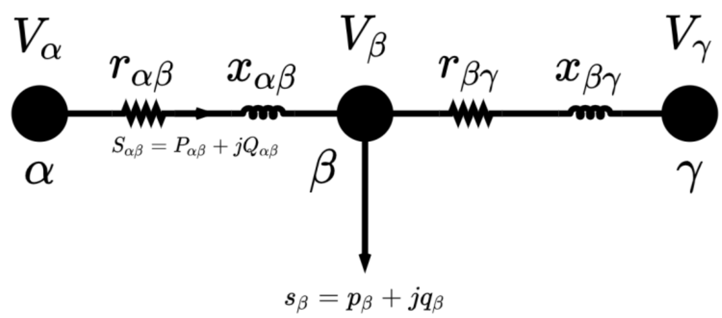
To understand dynamic operating envelopes, it is necessary to understand how we model and analyse the behaviour and performance of electricity distribution networks. This section, therefore, provides a high-level overview of how we develop mathematical models of electricity distribution networks. For a more in-depth mathematical treatment of the modelling and analysis of electricity distribution networks, we refer the reader to the references contained within this report.

An electricity distribution system is largely characterised by a “node and branch” model, where the branches represent the physical assets in the network including lines, transformers and protection equipment and the nodes represent the points of interconnection. Nodes in the network where customers obtain their electricity supply are typically referred to as connection points, and usually associated with both a meter and NMI for market operation and participation purposes.

Most electricity distribution networks in Australia are configured and operated in a radial topology, meaning that there are no ‘loops’ in the distribution network and energy can only flow down a unique path between locations in the distribution network. For illustration purposes, for a radially operated electricity distribution network, we can use the node and branch characterisation outlined above is used to develop our distribution network model (Figure 8).



(a) For the purposes of this study, an electricity distribution system is largely characterised by nodes and branches, where the branches represent the physical assets in the network including lines, transformers and protection equipment and the nodes represent the points of interconnection. We refer to this information as the topology of the network. It is worth noting that many of these points of interconnection correspond to locations where customers connect to the distribution network and are associated with both a market meter and a NMI.



(b) Once we have the network topology, it is important to understand the electrical characteristics of the network assets which includes the conductor impedance (resistance and reactance). When modelling the nodal power injections and branch power flows in a network we typically assume them to be a constant real and reactive power over the time interval (typically 5 or 30 minutes).

Figure 8. Mathematically modelling the behaviour of an electricity distribution network. We note that the critical data needed to model and analyse these electricity distribution networks relates to their topology (how the physical assets are interconnected), and the electrical characteristics of those assets which includes the conductor impedance and transformer specifications.

Voltage Constraints

Within the distribution network, there are prescribed voltage limits specified. These limits correspond to voltage limits for all of the nodes within the distribution network at a given voltage level. Depending on the voltage level within different segments of the electricity distribution network there is typically a nominal, upper and lower voltage limit. For example, in low voltage electricity distribution networks where most residential customers are connected the Australian voltage standards[7] are shown in Table 1.

Australian Low Voltage Standards	Voltage
Nominal	230V
Upper Limit (+10%) ($V_{\max}$)	253V
Lower Limit (-6%) ($V_{\min}$)	216V

Table 1. The standard voltage levels for Australian electricity distribution networks

The requirement for electricity distribution networks to remain within these voltage limits corresponds to the following inequality being simultaneously true for all of the nodes within the electricity distribution network.

$$V_{\min} \leq V_{\alpha} \leq V_{\max}$$

It is useful to appreciate that the voltage of each node in a network is influenced by power injections at other nodes in the network that share a common electrical path (Figure 9). More concretely, the sensitivity of the voltage at one node to real or reactive power injections at another node is related to the resistance and reactance of this common electrical path. This means that both nodes 'upstream' and 'downstream' of a node are able to impact the voltage behaviour at a node. This has important implications when designing mechanisms to prevent operational breaches of the voltage limits.

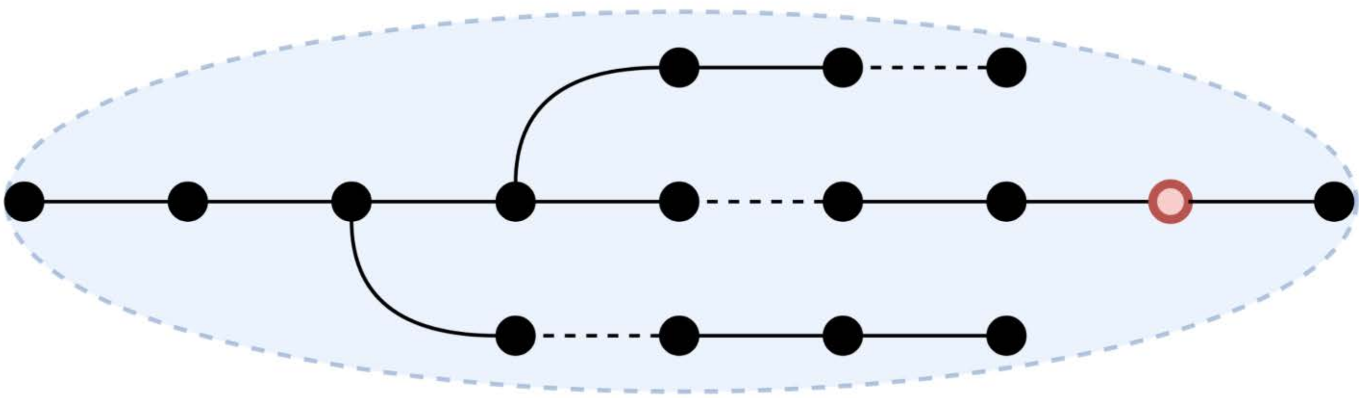


Figure 9. Nodes both upstream and downstream of a given node (in the blue region) will contribute to changes in the voltage at the critical node (coloured here in red). Technically, injections at a given node will change the voltage at another node if there is a common electrical path.

As a guide, nodes that are closer to the end of an electrical network will tend to experience voltage violations first. This is a consequence of greater electrical resistance and reactance which is a consequence of a longer electrical path. In saying this, the increasingly dynamic flows of real and reactive power caused by DER mean that voltage violations are increasingly possible at almost any node in a distribution network.

Thermal Constraints

The other primary physical constraint in distribution networks are thermal limits. Thermal limits represent limits on the apparent power in a branch of the electricity distribution network. These limits vary widely depending on the asset type (i.e. conductor, transformer, etc..) and the asset specifications (i.e. conductor size, etc…).

Both real and reactive power contribute to the apparent power flowing through a branch in a distribution network. This is an important consideration as the manipulation of reactive power produced or consumed

[7] Australian Standard AS60038-2012

by DER assets to manage voltage constraints has the potential to increase the likelihood of breaching thermal constraints.

The requirement for electricity distribution networks to remain within these thermal limits is thus captured by the following inequality condition being simultaneously true for all of the branches within the electricity distribution network.

$$P_{\alpha\beta}^2 + Q_{\alpha\beta}^2 \leq (S_{\alpha\beta}^2)_{\max}$$

In contrast to voltage constraints, only nodes downstream of a branch can contribute to violations of thermal limits in a given branch (Figure 10).

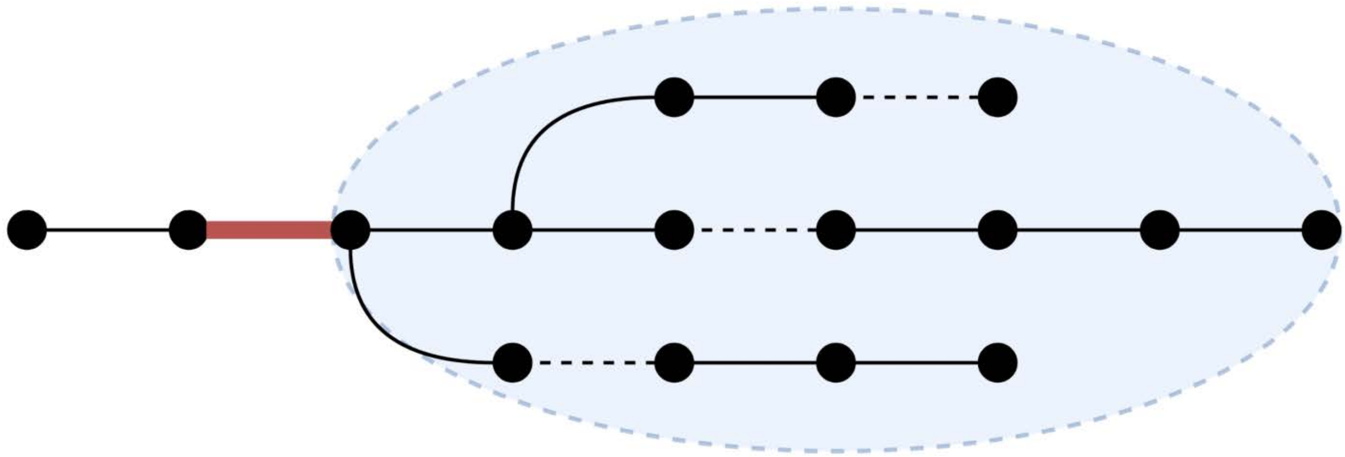


Figure 10. Only nodes downstream of a branch (in the blue region) will contribute to the apparent power of a given branch.

Analysing Electricity Distribution Networks

To ensure that electricity distribution networks are operated within their physical and operational voltage and thermal limits, there has been considerable research in the area of DER hosting capacity analysis as well as in the development of active network management strategies.

Hosting Capacity

Hosting capacity analysis refers to methods that quantify the amount of DER that can be installed and operated in a distribution network without breaching physical or operational limits. Hosting capacity analysis can be deterministic or probabilistic and can be undertaken using a variety of different powerflow models and analysis methods.

When undertaking such analysis, the hosting capacity is determined as the point when any additional powerflow within the network would result in a breach of the physical or operational limits of the network. The node voltage or branch powerflow that would be in breach of its technical or operational limit in this circumstance is said to be the binding constraint.

While hosting capacity analysis is often used to quantify the amount of un-orchestrated DER that can be installed, if it is desirable to install or operate more DER, then it is necessary to either build additional network infrastructure or to control the installed DER. In the latter case, the development of active network management strategies provides the operational mechanisms by which DER can be actively controlled to prevent breaching physical or operational limits.

Active Network Management

Active network management strategies have been defined for both voltage and thermal constraints using a variety of centralised, decentralised and distributed approaches. Ultimately, the concepts of hosting capacity and active network management strategies are often deeply related. Given that an active network management strategy is likely to define the behaviour of DER as the physical or operational limits are approached, the active network management strategy often implicitly or explicitly determines the DER hosting capacity that can be achieved within a given distribution network segment.

Overwhelmingly, active network management strategies (including volt/var and volt/watt settings in inverters) are focussed on providing setpoint control for DER. That is, they are focussed on determining the exact value of the DER output that will best allow some operational objective to be achieved. In contrast, dynamic operating envelopes provide a range of DER behaviours (referred to as nodal limits on real and reactive power injection or demand) that will ensure that physical and operational limits are not breached. In this way, operating envelopes effectively represent the translation of physical and operational voltage and thermal constraints into nodal real and reactive limits for each participating node within a given distribution network segment.

5. What is an Operating Envelope?

An operating envelope is the simultaneous, extreme nodal DER or connection point behaviour (i.e. real and reactive power injection or demand) that can be accommodated before physical and operational limits of a distribution network are breached. An operating envelope essentially provides upper and lower bounds on the import or export power in a given time interval for either a DER asset or a customer connection point. Various illustrative operating envelopes are depicted visually in Figures 11 – 13 and outlined in the sections that follow.

Real-Power Operating Envelopes

The simplest operating envelope translates either or both network thermal and voltage constraints into real power limits (Figure 11) at each participating DER asset or customer connection point. Such an operating envelope may be appropriate for DER assets that can only produce real-power outputs (i.e. some solar inverters) or when achieving non-unity power factor control for a given DER asset or connection point is not possible.

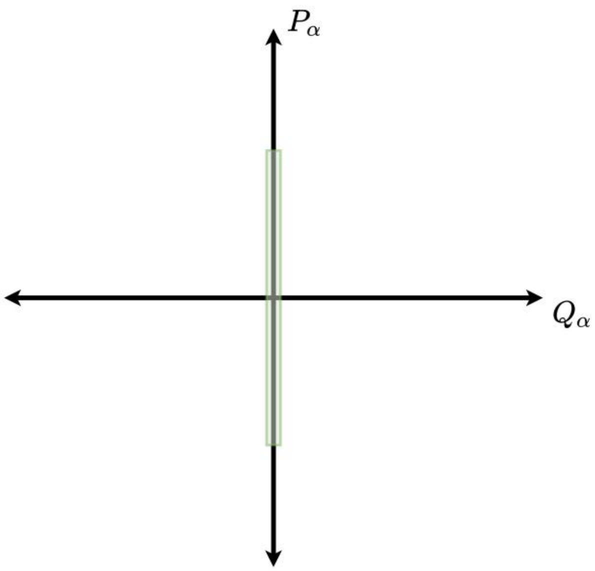
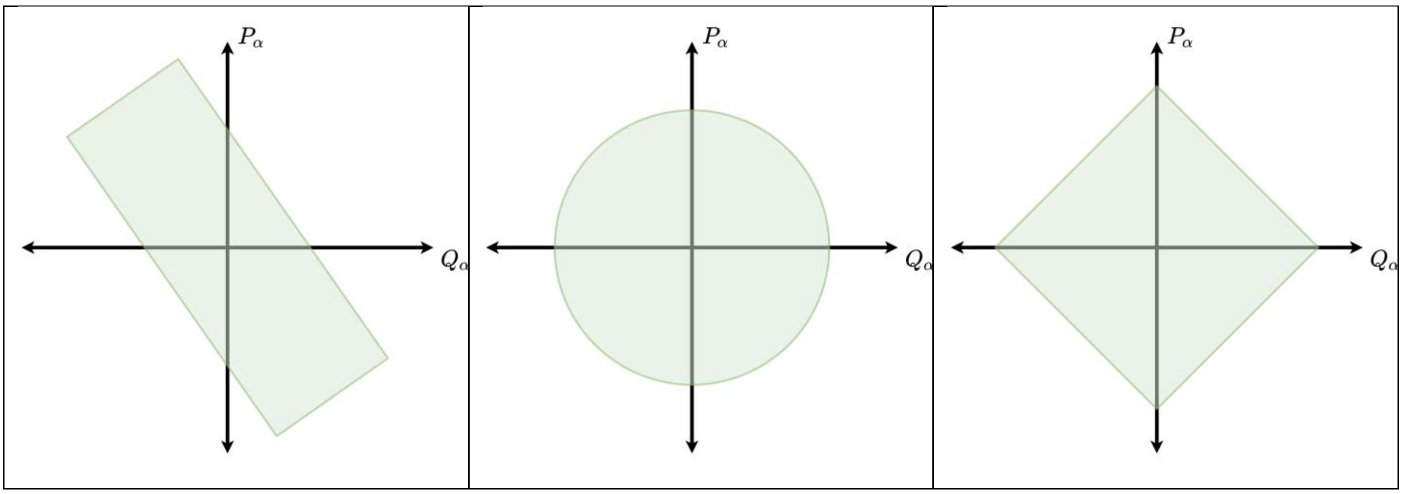


Figure 11. An illustrative operating envelope for an individual DER asset or connection point that only provides real power

Real- and Reactive- Power Operating Envelopes

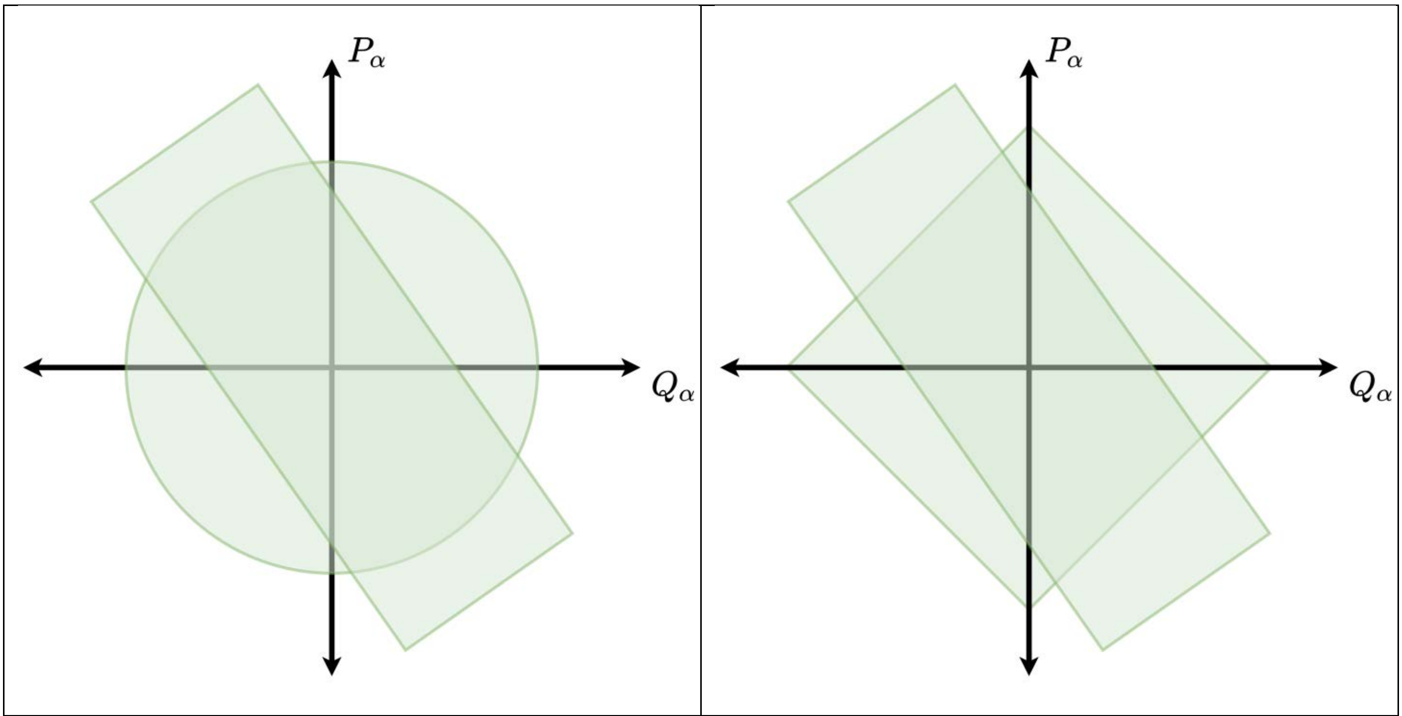
A far more useful operating envelope will provide nodal limits for both real and reactive power (Figure 12 and 13). We can represent these limits as the region in which individual DER or connection points can vary their combination of real and reactive power. The simpler the shape that represents these joint limits, the easier it is for DER to enact these operating envelopes in practice.



(a) An operating envelope for an individual node when voltage limits represent the binding constraint.	(b*) One way of representing the operating envelope for an individual node when thermal limits represent the binding constraint.*	*(c) An affine way of representing the operating envelope for an individual node when thermal limits represent the binding constraint.*

Figure 12. Various illustrative operating envelopes that would arise at an individual node when network voltage or thermal constraints are considered independently.

In Figure 12, we can observe the real and reactive power operating envelopes that arise for both network voltage and thermal limits separately. Figure 13 then shows these limits jointly applying, where the intersection of the two regions, represents the operating envelope. It is worth noting that these diagrams are illustrative only, and will depend on the mathematical formulation of the operating envelope problem and the allocation method used. Both of these concepts are discussed in greater detail in the sections that follow.



(a*) The intersection (darker green) of the individual voltage and thermal constraints represents the operating envelope at a node. In this case the operating envelope is based on the circular form of the thermal constraint.*	*(b) The intersection (darker green) of the individual voltage and thermal constraints represents the operating envelope at a node. In this case the operating envelope is based on the affine form of the thermal constraint.*

Figure 13. Illustrative operating envelopes that would arise at an individual node when both network voltage and thermal constraints are considered jointly.

As shown in Figures 11 - 13, an operating envelope provides bi-directional (both upper and lower bounds) for real power, or for both real and reactive power. The bi-directional nature of an operating envelope accommodates their use for a variety of different use cases which are covered in the following section.

An operating envelope is specified in time intervals (typically to align with market intervals) over a forward time horizon (typically 24 hours). An operating envelope is communicated to DER assets using an API specification that is included in the Appendix.

To provide flexibility, operating envelopes can be specified at either customer connection points or at the terminals of the DER assets themselves (Figure 14).

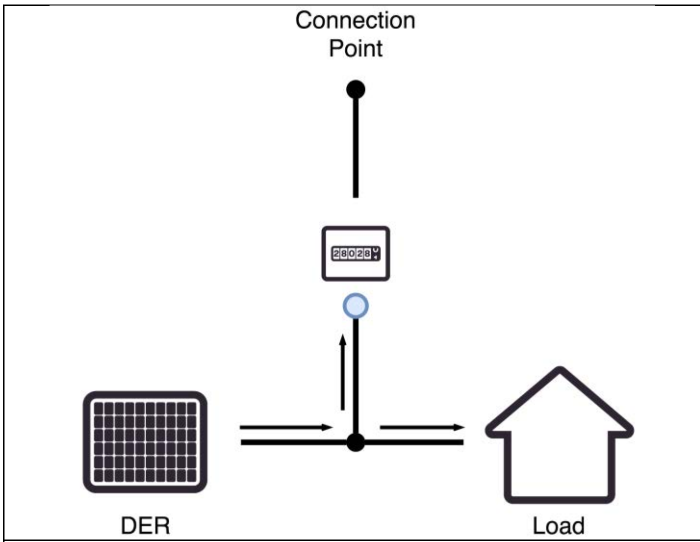
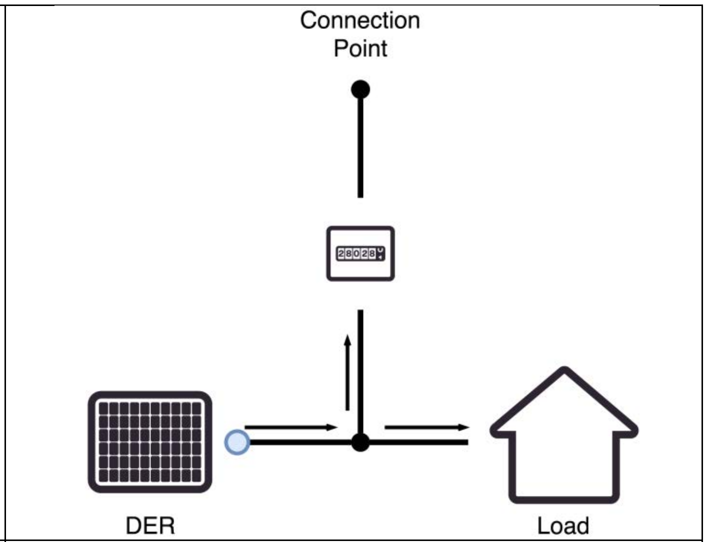
	
(a) An operating envelope can be specified at a customer connection point. In this case, the sum total of behind the meter power flows must remain within the operating envelope specified.	*(b) An operating envelope can also be specified at the terminals of an individual DER asset.*

Figure 14. Operating envelopes can apply either at the connection point (a) or at the terminals of the DER assets themselves (b).

Use Cases

Dynamic operating envelopes have the potential to achieve multiple operational goals for network operators. Indeed, this is one of the key benefits of defining operating envelopes bi-directionally. The key use cases are detailed below.

Managing Solar Generation (Export)

One of the key use cases for dynamic operating envelopes is to ensure that physical and operational distribution network limits are not breached during periods of peak solar generation. An operating envelope helps in this instance by signalling the need for reduced generation or for an overall reduction in export from a customer connection point.

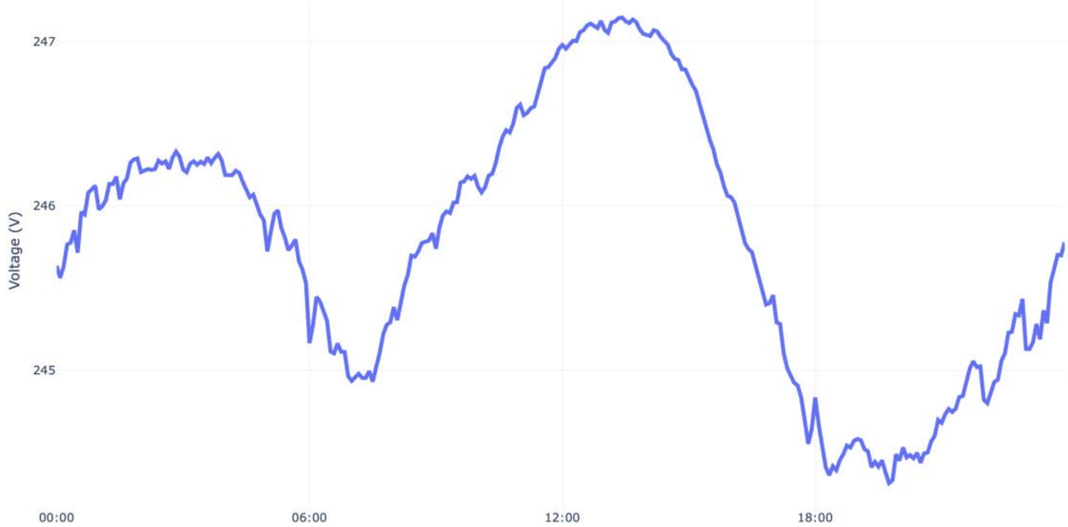
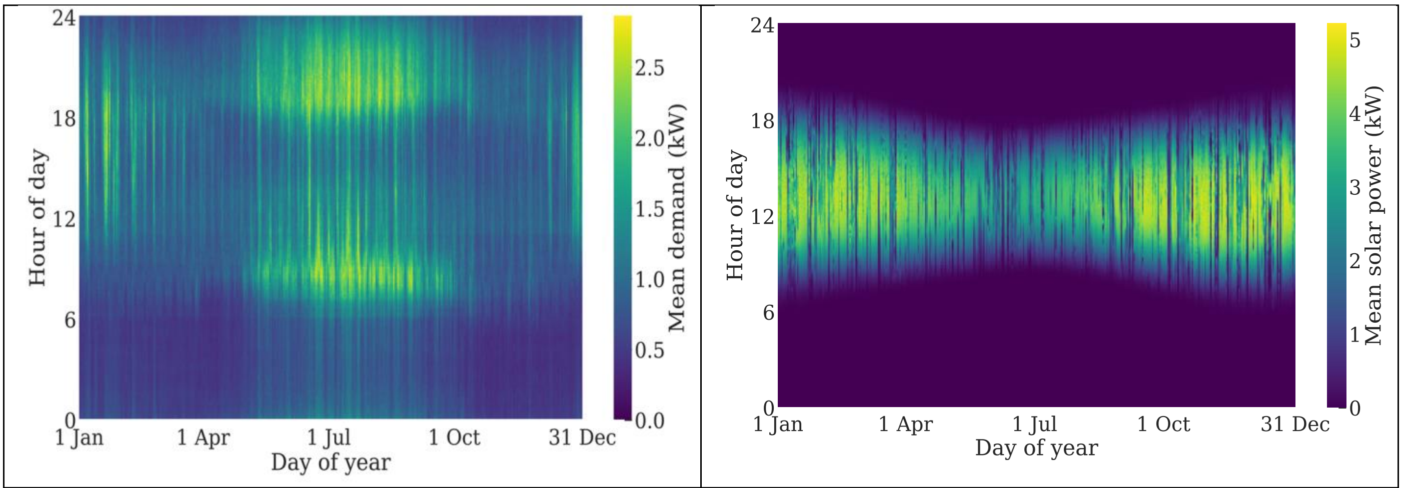


Figure 15: The average voltage on the network tends to be highest during the middle of the day when solar generation is at its peak. Data is the average daily voltage profile for 2018 from customers participating in the ACT NextGen Battery Program.

It is worth noting that peak solar generation is only likely to breach physical or operational limits when the underlying demand is low, and when solar generation is at its peak. In many areas this means that during the middle of the day (Figure 15) in mild spring and autumn days when demand is low (when heating and cooling are not necessary) (Figure 16), is likely to be when operating envelopes will be most operationally useful to address this particular use case.



(a) The mean demand for approximately 800 customers participating in the ACT NextGen Battery program in 2018.	*(b) The mean solar generation for approximately 800 customers participating in the ACT NextGen Battery program in 2018.*

Figure 16. The need for operating envelopes in spring and autumn is clearly demonstrated in these images where it can be seen that in spring and autumn there is low underlying demand (a) but almost full solar generation capacity in the middle of the day (b). These conditions create a circumstance where highly correlated reverse flows of energy will occur, which has the potential to result in breaches of both voltage or thermal limits.

For customers with both solar PV and batteries, the operating envelope signals implicitly that it is better to defer charging of the battery until peak periods of energy generation (i.e. during the middle of the day). This example highlights one of the advantages of dynamic operating envelopes in that they provide clear signals to customers about how to modify DER asset behaviour, without being prescriptive about how this is achieved. Deferring battery charging in this way to soak up solar generation when it might cause network voltage or thermal breaches is unlikely to reduce net generation, nor impact the ROI of solar PV or battery storage.

EV Charging (Import)

While electric vehicles uptake is only starting to occur, if all cars became electric there could be significant consequences to the correlated charging of electric vehicles in the evening. In a similar way to dealing with solar generation, an operating envelope would provide a clear signal to customers to defer, or reduce the power of EV charging to avoid breaching voltage or thermal constraints.

DER Market Participation (Both Import and Export)

One of the key use cases identified for dynamic operating envelopes is that the additional network capacity can be used by DER assets to participate in markets for energy and ancillary services. By publishing an operating envelope, DER assets can participate in markets only up to the limit of the operating envelope. This ensures that market participation cannot infringe the safe and secure operating limits of the electricity distribution network. In circumstances where network limits will potentially result in constrained dispatch of DER in markets for energy and ancillary services, operating envelopes will provide valuable forecasts of available network capacity. This will ensure that forward DER bids in markets for energy and ancillary services are firm.

Ultimately, it is this use case that provides the reason for aligning the time interval of an operating envelope with the time interval of the market. This means that envelopes are currently considered to be 30 minutes long, although this will change as the market settlement interval in Australia, moves to 5-minute settlement from 1st October 2021[8]. A diagrammatic explanation of the relationship between operating envelopes and markets for energy and ancillary services can be seen in Figure 17.

[8] https://www.aemc.gov.au/rule-changes/delayed-implementation-five-minute-and-global-settlement

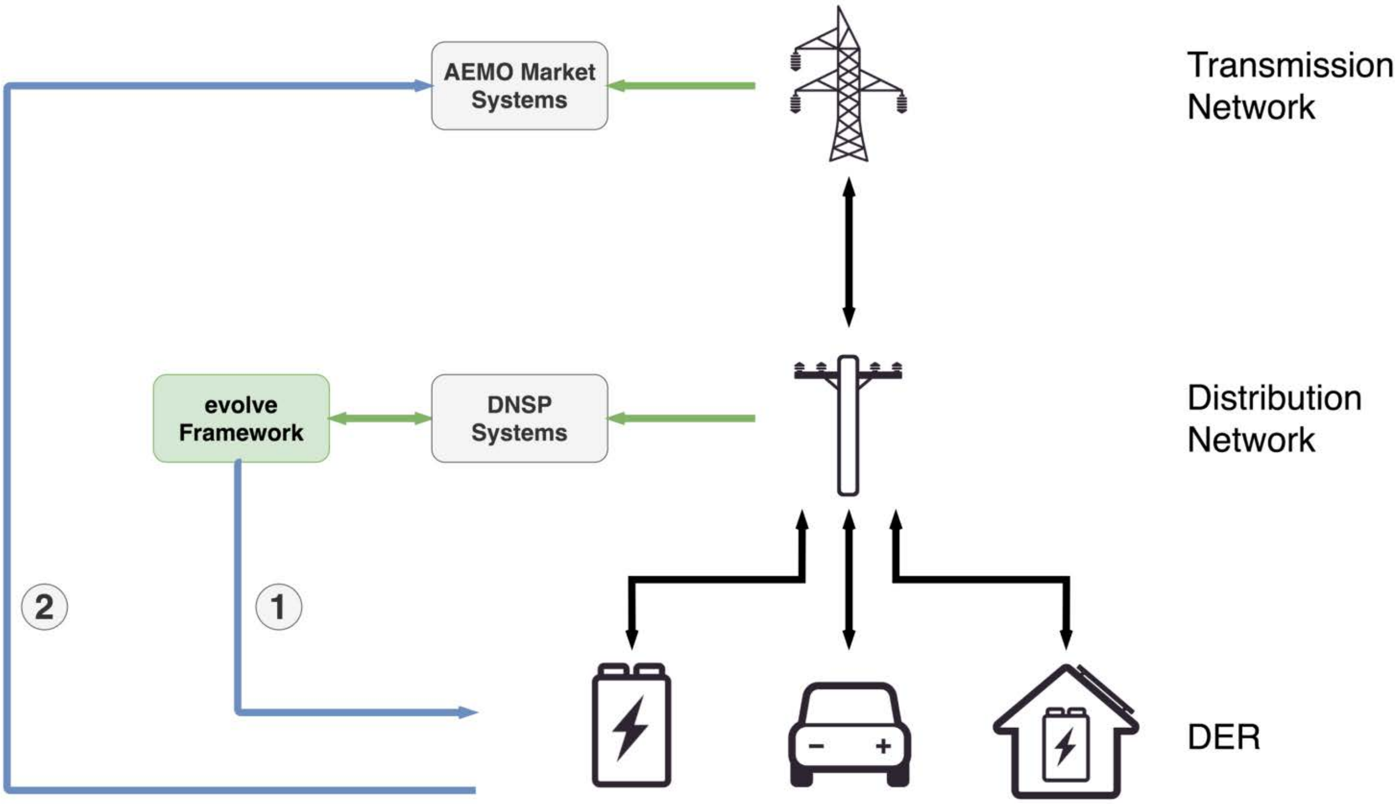


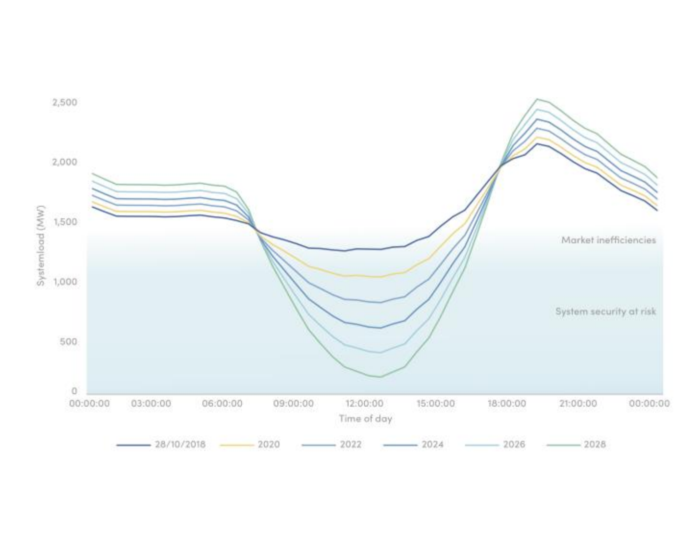
Figure 17. The use of dynamic operating envelopes allows DER to bid into markets for energy and ancillary services without breaching physical or operational limits of electricity distribution networks. In this diagram, green lines correspond to operational monitoring data and network visibility, whilst blue lines correspond to the sequence of actions being demonstrated through the evolve project.

In the evolve Project, this use case will be demonstrated in the following manner. DER will be sent operating envelopes (Step 1) before separately bidding into AEMO markets (Step 2).

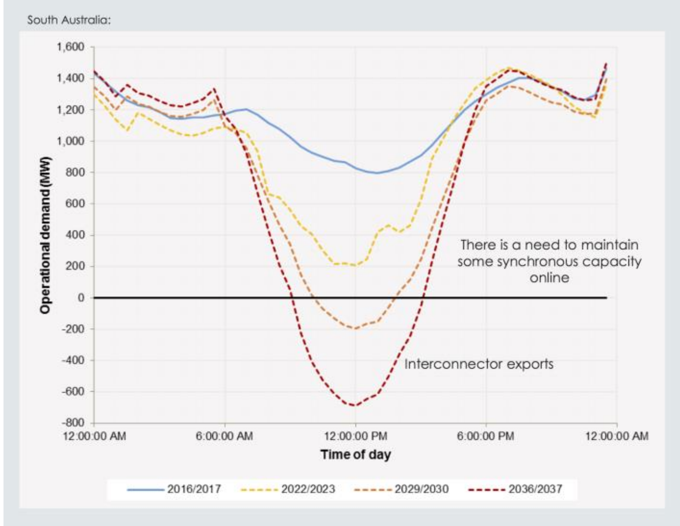
Using Operating Envelopes to Maintain System Security

While the evolve project is focussed on the development of operating envelopes to ensure that physical and operational network limits are not breached, there is emerging interest in the use of operating envelopes to help maintain system security limits during periods of high solar generation.

The reduction in minimum demand for both SA and WA can be seen in Figure 18 which will require solutions that may include solar curtailment, something that could be accomplished using operating envelopes. In this instance, the signal for operating envelopes could be published using the same mechanisms described previously but the source of information to define the operational security constraint would be sourced from AEMO systems. To accommodate this use case an additional data integration would therefore be needed with AEMO (Figure 19).



(a) Forecast minimum demand in WA over the decade ahead. [9]



(b) Forecast minimum demand in SA over the decades ahead. [10]

Figure 18. Understanding how to maintain energy security is an increasingly urgent challenge as several locations in Australia, in this case Western Australia and South Australia, are headed towards negative minimum demand over the coming decades.

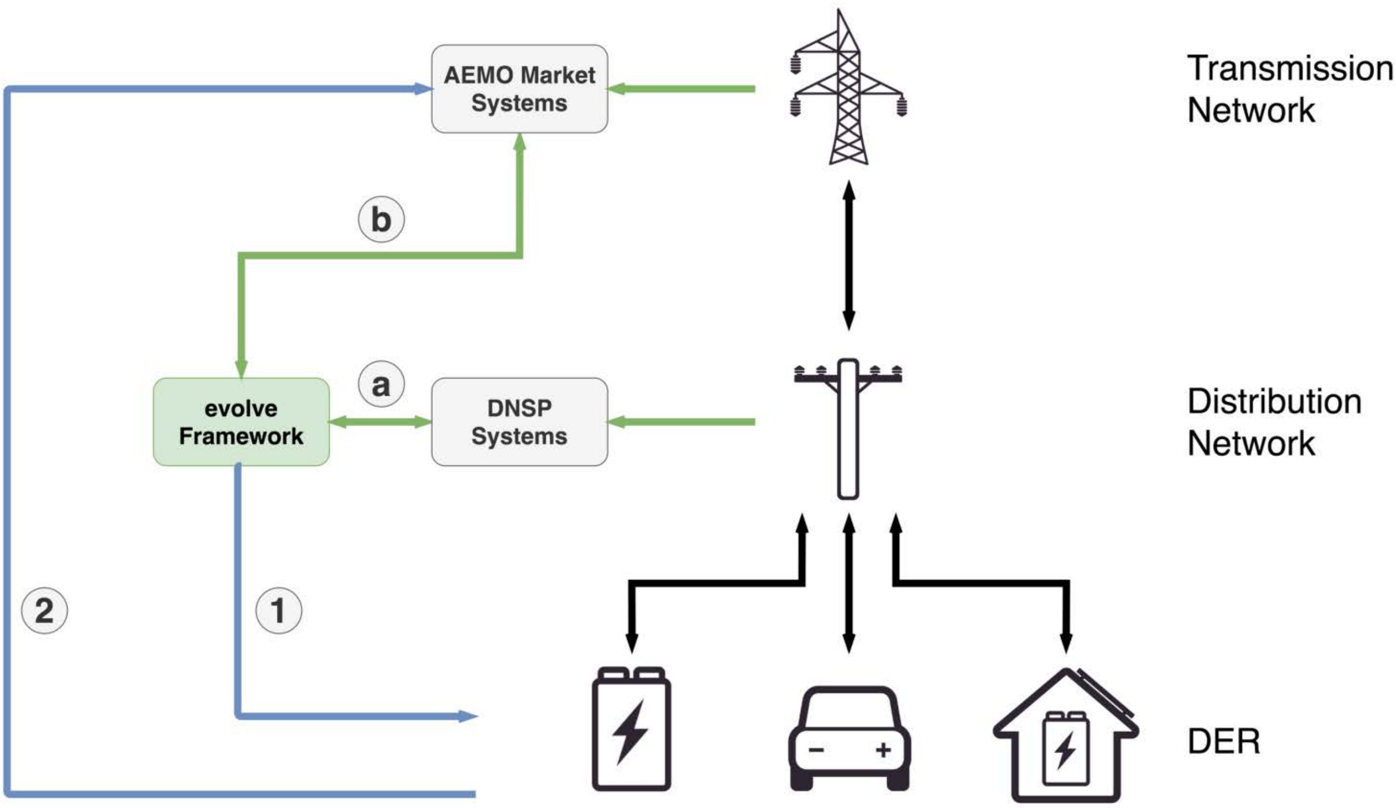


Figure 19. Operating envelopes could be used to manage system security constraints but this would require an additional integration with AEMO systems. If operating envelopes were also used to address system security concerns then the operating envelope algorithm would be updated to jointly solve for network voltage and thermal constraints and system security constraints.

We anticipate that there may emerge additional operational use cases for operating envelopes over the coming decade which for example may include better managing power transfer stability limits.

---

[9] https://www.wa.gov.au/sites/default/files/2020-04/DER_Roadmap.pdf

[10] Riesz, Integration of DER: Operational Impacts, Future Electricity Markets Summit, Sydney, 2019.

Timescales of an Operating Envelope

Given the relationship / correspondence between the hosting capacity and operating envelopes, it is possible to imagine that the concept of an operating envelope can extend beyond the operational time-domain into longer network planning time domains. This concept is captured in Figure 20.

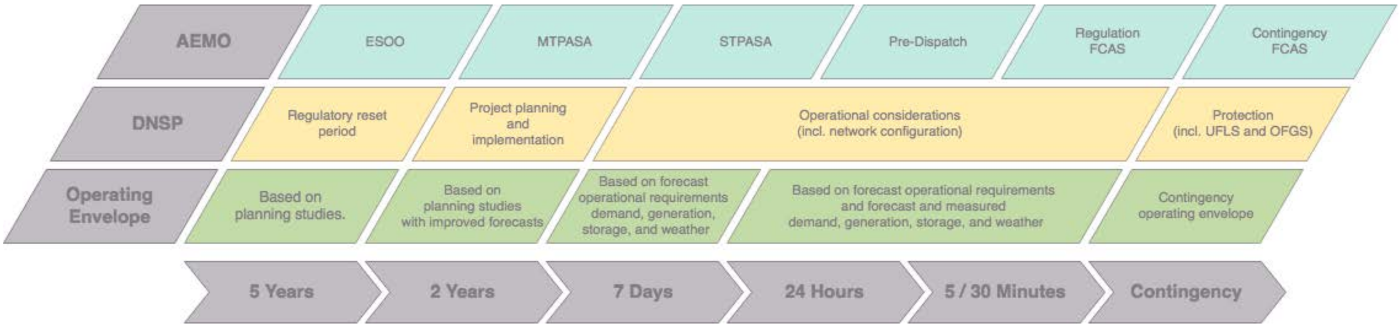


Figure 20. An operating envelope is not just an operational concept, it also relates to longer term network and market planning domains.

What an Operating Envelope is Not!

As detailed above, an operating envelope is a principled allocation of the available network capacity to individual or aggregate DER or connection points. We believe that an operating envelope must thus represent an *allocation of all available network capacity* up to the physical and operational limits of the network.

Outside of preventing breaches of the network physical and operational limits, we do not believe that an operating envelope should be used to:

- Restrict customer DER connection approvals
- Restrict or reduce energy export from DER assets as a component of new connection standards nor remove the rights of DER assets to participate in the delivery of energy and ancillary services that support energy reliability and security.

It is important to note that an operating envelope represents a range of allowed DER or connection point behaviour and should not be used to provide pseudo set-point control. If more fine-grained, DER or connection set-point control is required (i.e. for network services, augmentation deferment, etc…) then appropriate economic or market-based incentives should be used.

To ensure that operating envelopes are not used for purposes other than those intended, we anticipate that it will be necessary for regulations to be introduced that require or incentivise some minimum DER hosting capacity. These regulations will ensure there is a healthy tension that results in available hosting capacity and operating envelopes that balance the socialised cost of network infrastructure whilst ensuring that customers can continue to invest in and adopt DER assets.

6. Method of Calculation

There are multiple algorithmic approaches by which an operating envelope may be calculated mathematically, and these different approaches depend on how the behaviour of the distribution network and DER behaviour are modelled. However, to produce a valid operating envelope, the calculation methods must appropriately capture the alternating current (AC) physics of the electricity grid and must be calculated with reference to the physical and operational network limits, which at a minimum include the voltage and thermal constraints outlined previously. Irrespective of the choice of mathematical model or algorithm, the steps necessary to calculate an operating envelope in each time interval are captured within Figure 21 and detailed in the subsections that follow.

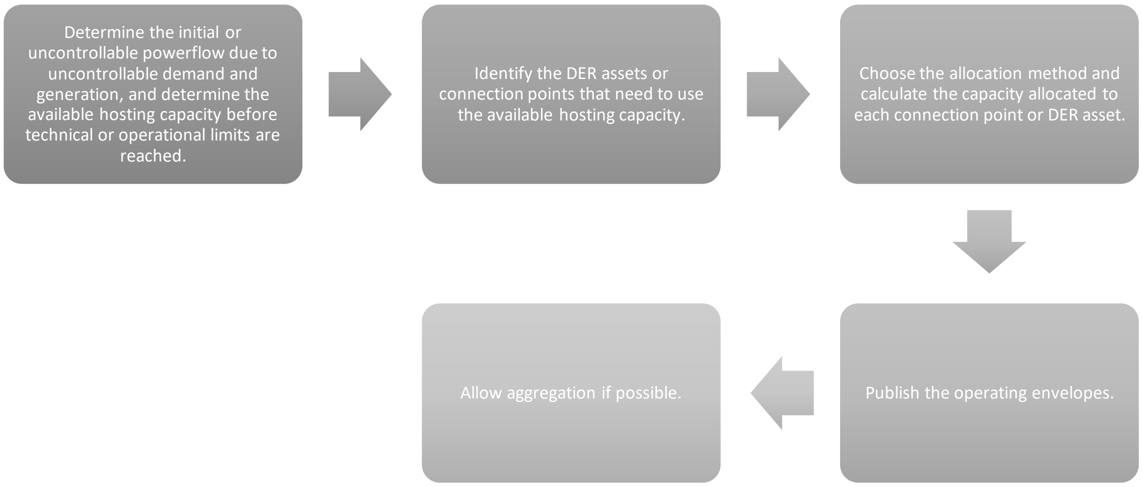


Figure 21. The steps necessary to calculate an operating envelope.

Determine the Initial or Uncontrollable Powerflow

It is important to realise that as dynamic operating envelopes represent a form of active network management, they can only be utilised for DER assets or connection points that are able to respond to external signals. In this context, to identify the available hosting capacity it is necessary to first determine the initial operating state of the network due to uncontrollable demand and generation flows. Given the limited visibility that many networks have on the operation of the distribution network, and the absence of accurate network models or conductor data, it may be necessary to use some form of state estimation to approximate the initial operating state of the network.

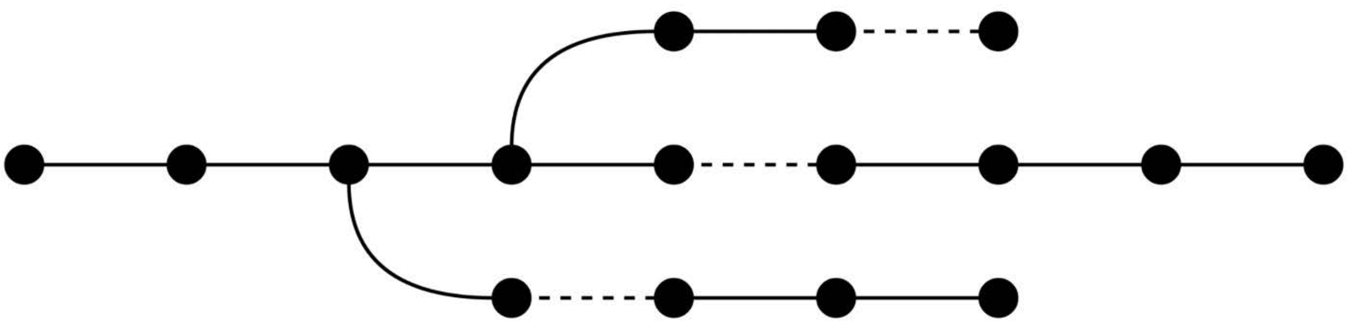


Figure 22. We determine the available capacity by first determining the initial operating state of the network by measuring or forecasting the powerflows due to uncontrollable demand and generation from all nodes in the network.

As operating envelopes are also provided over the forward horizon, it will often be necessary to calculate a forecast of the initial operating state of the network due to uncontrollable demand and generation in future time intervals. Once the initial, or forecast future initial, operating state of the network is known, it is possible to determine how much network capacity remains to be allocated via dynamic operating envelopes.

Identify the DER Assets or Connection Points

To allow the remaining network capacity to be allocated it is important to know the network location of the DER assets or connection points to which the remaining capacity will be allocated (Figure 23). This requirement arises due to the non-trivial relationship between DER or connection point location in the network, the injected real and reactive power at each node, and the resultant node voltages and branch flows in the electricity distribution network.

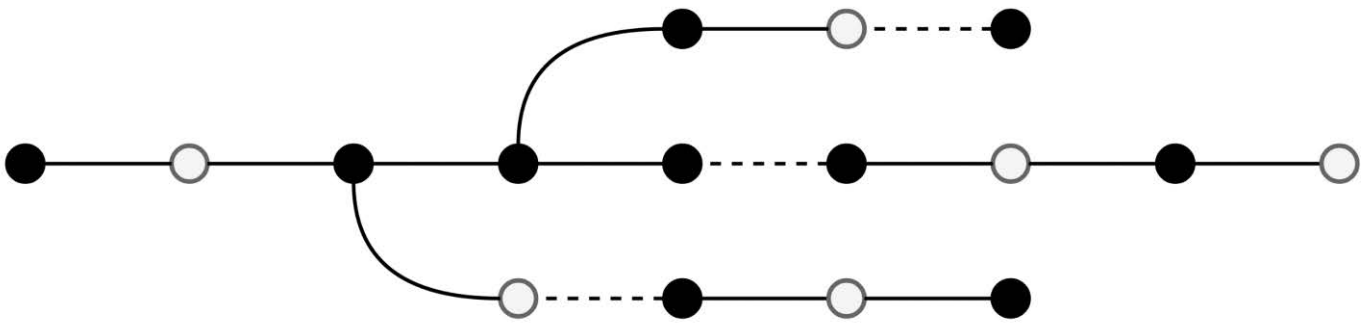


Figure 23. The network location (grey nodes) of the DER assets or connection points to which this remaining network capacity will be allocated.

Calculate and Allocate the Available Hosting Capacity

Once the initial operating state of the network is measured or forecast it is possible to calculate how to allocate this remaining network capacity. Almost always there will be infinitely many ways of allocating this remaining capacity so it is desirous to choose an allocation principle. Some possible allocation principles include:

- An equal allocation of real and reactive power capacity to each participating DER asset or connection point.
- An allocation of real and reactive power capacity that equally impacts voltage rise or fall at the location of the binding constraint. Such an allocation would significantly favour network locations close to the upstream transformer so is likely to be considered unfair.
- An allocation of real and reactive power capacity that relates to the marginal cost of generation.
- An allocation of real and reactive power capacity based on the energy or ancillary service bid price. This allocation would effectively correspond to the creation of a DER merit order effect in markets for energy and ancillary services.

The choice of allocation principle here corresponds directly to the notion that an operating envelope represents a principled allocation of the available network capacity. With this allocation principle in hand it is possible to then use one of several mathematical algorithms to calculate the dynamic operating envelope for each DER asset in each time interval over the forward horizon. These mathematical algorithms can include:

- Linearisation of the Jacobian around the initial operating point of the network [11].
- Analytic solutions based on the powerflow formulation for radial distribution networks[12].
- Optimisation based methods[12].

For full details of these methods, the reader is referred to the more complete mathematical formalism contained in each of the referenced articles.

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[11] Mahmoodi et al., Generation Hosting Capacity of DER in Unbalanced Distribution Systems, Under Review.
[12] Blackhall et. al., Dynamic Operating Envelopes for Radial Distribution Systems, In Preparation.

Publish the Operating Envelope

Once the remaining network capacity has been allocated to each DER asset or connection point, it remains to publish the capacity, in the form of an operating envelope over a rolling 24hr period. In the evolve project, operating envelopes are communicated via an API based on the IEEE2030.5 standard through an IEEE2030.5 Utility Server, which is detailed further in the sections that follow.

Aggregate

The notion of an operating envelope also admits the ability to aggregate up operate envelopes between DER assets or connection points. It should be noted that such aggregation cannot occur arbitrarily within the entire electricity distribution network and can only be allowed in aggregation zones, which will typically correspond to particular segments of an electricity distribution network. Even within a given aggregation zone, the notion of aggregation is not a straight summation but requires additional calculations to be undertaken. Notwithstanding this additional calculation requirement, the ability to allow retailers or aggregators to aggregate within their own customer base provides important flexibility to achieve specific individual and aggregate optimisation outcomes.

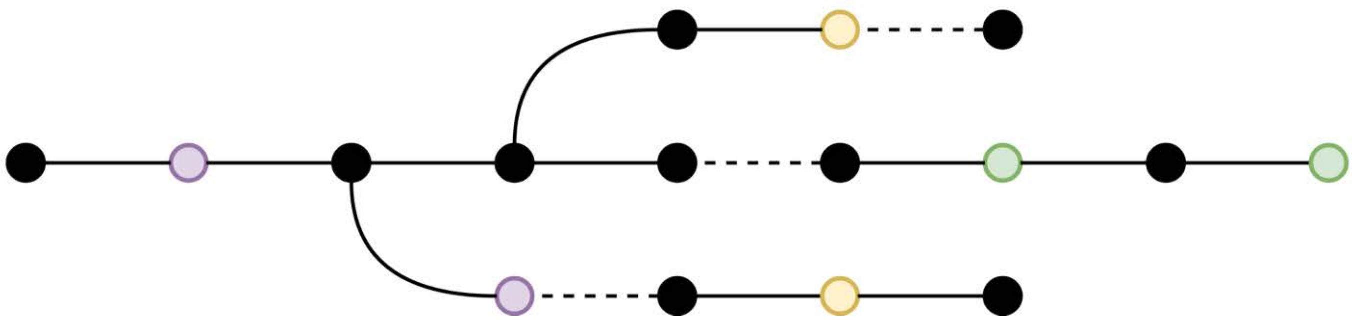

Figure 24. As an illustrative example, we see in this diagram that our six DER sites are managed by three different aggregators, each with two DER assets or connection points under management. The notion of an operating envelope allows the individual operating envelopes to be aggregated between customers with a common retailer or aggregator. Aggregation is not a straight summation of the individual operating envelopes and requires further calculations to be undertaken. These calculations can however be performed by individual retailers or aggregators after the operating envelopes are published.

7. Benefits of Operating Envelopes

It is important to recognise that operating envelopes represent only one mechanism by which DER integration can be achieved without threatening the physical or operational limits of electricity distribution networks. Notwithstanding this, there are several benefits of operating envelopes given the current maturity levels of DER deployed within the Australian electricity system.

Firstly, operating envelopes are able to address a diversity of different operational use cases. These potential use cases were discussed in a previous section and encompass operational challenges for preventing breaches of network physical and operational limits as well as mechanisms for managing systems security challenges due to minimum demand. Going forward there is significant potential for using dynamic operating envelopes to address other emerging network and system operational challenges.

Secondly, by design, operating envelopes promise to be simple to implement across a variety of different DER assets, and do not require the use of sophisticated local optimisation and control systems. This has the potential to increase adoption and compliance across the diversity of DER assets installed in Australian distribution networks. Nonetheless, operating envelopes do not preclude the use of sophisticated local optimisation and control systems. Where such local optimisation and control systems are deployed, operating envelopes represent an additional optimisation constraint that can be easily incorporated into the optimisation and control algorithms used by DER manufacturers and aggregators. Furthermore, as operating envelopes do not prescribe the set-point of DER assets or customer connection points, operating envelopes provide flexibility for DER assets and connection points to optimise within operating envelopes to achieve other local or market participation objectives.

Thirdly, operating envelopes can be deployed progressively into different segments of a distribution network. This incremental approach to testing, validation and deployment reduces operational risks for networks. Furthermore, by definition, dynamic operating envelopes are dynamic and can be updated as frequently as needed. This provides important operational flexibility for networks and system operators in responding to unforeseen events caused by operational or environmental (i.e. weather) considerations.

Towards Transparent Network Planning and Operation

One of the direct benefits from the adoption of operating envelopes is the broad uplift in capabilities for distribution networks to be able to calculate and publish the available network capacity. This requires an uplift in network visibility, including in capturing network topology and electrical characteristics.

Operating envelopes also provide a mechanism to allow transparent reporting (i.e. by prosumers and VPPs) about the impact of limited hosting capacity, particularly for DER assets participating in markets for energy and ancillary services. By capturing the difference between potential market bids, and the available network capacity (as quantified through a dynamic operating envelope), it is possible to understand the lost value of DER participation in markets for energy and ancillary services. This quantification will be a valuable insight for broad network planning considerations, as well as when considering the use of network services to alleviate network congestion. Ideally, such an outcome empowers DER customers to play a central role in justifying network planning decisions into the future, which is a key element of how network tariffs are calculated. More efficient planning mechanisms could reduce electricity costs for all customers.

The evolve project will also demonstrate how we can better understand the geographic limits and opportunities for DER based on existing network infrastructure. This further empowers customers to make decisions about the acquisition of DER assets. Customers will have a better understanding of the value that those individual assets can provide in different segments of a given electricity distribution network.

Finally, beyond the evolve project, but building upon the notion of dynamic operating envelopes, we believe that opportunities will emerge that allow the trading of hosting capacity. This includes creating opportunities for community energy models and may also help address equity issues between those who have DER devices and those who don’t by allowing operating envelopes to be traded between consumers and prosumers.

8. Implementation

The implementation of dynamic operating envelopes being pursued through the evolve project is built on six key pillars (Figure 25), representing the three overarching themes of technical capabilities, social license and rules and regulations.

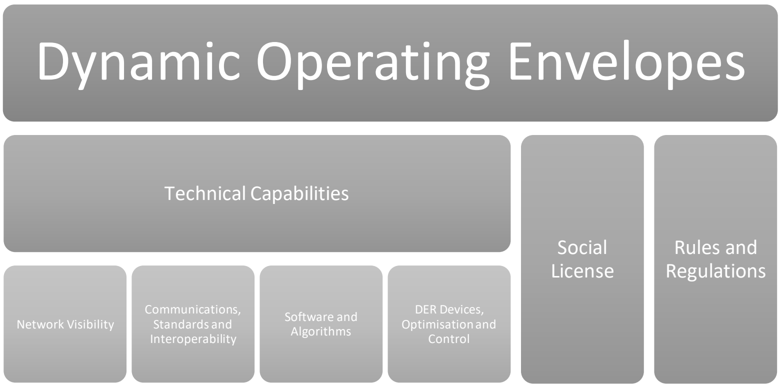

Figure 25. The key pillars upon which the implementation of operating envelopes will be built.

These themes and pillars of implementation are explored in greater details in the sections that follow.

Technical Capabilities

The technical capabilities necessary to implement dynamic operating envelopes encompass four key areas:

- Network visibility
- Communications, standards and interoperability
- Software and algorithms
- DER devices, optimisation and control

Network Visibility

Increasing network visibility is central to the successful integration of DER in electricity distribution networks broadly, but is also a key requirement for the implementation of dynamic operating envelopes through the evolve project. Full network visibility is built upon three key capabilities:

1. Complete knowledge of the network topology and the electrical characteristics of the network.
2. Complete network monitoring.
3. Accurate forecasting capabilities for both indivudal and aggregate demand and generation sources.

Ultimately, complete network visibility allows the current and future operating state of the network to be fully determined, a pre-condition for calculating and publishing operating envelopes. For networks with full network models and complete advanced metering infrastructure (AMI) coverage, it may be possible to achieve near-complete network visibility. However, in general for many DNSPs, sufficient network and monitoring data will not be available to ensure complete network visibility. Furthermore, many networks are still to develop the operational forecasting capabilities necessary to satisfy the third point outlined above.

In circumstances where complete network visibility has yet to achieved there are several complementary approaches that can be pursued including:

- **enhanced network monitoring.** Enhanced network monitoring means increasing the use of dedicated network monitoring devices and also capturing data from smart meters and installed DER assets.
- **using alternate or additional data sources**. For example, customer characteristics (such as house type, size, location) may be used to infer the likely demand or generation that can be used for forecast generation.

- **implementing state estimation techniques**. In under-determined systems, state estimation techniques can use the available network topology, electrical characteristics, and monitoring data to continually infer and update the accuracy of the network topology, the network electrical characteristics and the power flows within the network.

4. **developing more sophisticated forecasting capabilities**. As operating envelopes in future time intervals depend on forecasts of the network operating state, accurate forecasting capabilities for both individual and aggregate demand and generation sources is vital.

The overall accuracy of operating envelope calculations will thus depend on the ability to achieve complete network visibility through the approaches detailed above. Further details about the operating envelope accuracy and available network visibility will be included in future evolve knowledge sharing reports as trials continue.

Communications, Standards and Interoperability

Given the dynamic nature of operating envelopes, there is a need to be able to communicate between the DER devices and local metering with the evolve framework, where the operating envelopes are being calculated. The form of this communication is not prescriptive and can be achieved using either the customer internet connection or via dedicated wireless connections (i.e. 3G / 4G). No form of communication is 100% reliable so care must be taken to ensure that DER devices are able to operate correctly when communications become unavailable.

The inherent unreliability of communications networks is one of the many reasons for providing an operating envelope over the forward horizon of up to 24hrs. In circumstances where a communications failure is experienced, the DER asset or connection point can continue to operate within the previously published operating envelope.

Alternatively, in circumstances or scenarios where there is concern about communications reliability it may be sensible to instead publish a more conservative default operating envelope. Upon a communications outage, the DER asset or connection point can revert to this default behaviour after a certain period in which it has no connectivity (and is thus offline)[13]. This default operating envelope approach ensures that communications failures do not result in DER or connection point behaviours that threaten the physical or operational limits of the network. A related approach to dealing with communications unreliability is to publish a very conservative operating envelope many days or weeks ahead, and then progressively increase the operating envelope closer to the current time interval.

To better understand the expected behaviour of given DER assets or connection points when communications reliability is a concern it may also be prudent to implement a multi-phase commit, or another form of consensus mechanism to ensure that the DER assets and the network operational technologies have a shared understanding of the expected behaviour of DER ahead of time. Under the assumption that offline systems continue to respect the most recent and acknowledged operating envelope definitions, an offline system would be considered as uncontrollable in future operating envelope calculations. As such, the extreme behaviour of the system could be included in the initial uncontrollable power flows on the network, which future operating envelope calculations for other DER assets or connection points must account for. The need to have a shared understanding of the expected DER or connection point behaviour is a reflection of the fact that with increasing decentralisation, the electricity system will behave increasingly like a distributed system and will require new techniques to be adopted. Crucially, many of these techniques have already been developed and implemented in large computer networks and systems, which are themselves highly distributed systems.

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[13] *The behaviour of DER assets experiencing communications outages is currently under consideration through the development of the Australian IEEE 2030.5 Implementation Guide by the DER Integration API Technical Working Group of which evolve project partners are founding members.*

Beyond the underlying communications capabilities themselves, the key to a successful implementation of operating envelopes at scale is the use of clear standards. Within the evolve project, and as part of the evolve framework, we are leveraging two key standards; namely the CIM and IEEE2030.5 standard for DER integration. Further details about both standards can be found in other evolve knowledge sharing reports.

Software Development

In the evolve project, network visibility is achieved within the open source evolve framework (Figure 26) by using the communications standards outlined in the previous section. The evolve framework has been developed to:

- Capture the network topology and electrical characteristics from DNSP systems using the CIM standard.
- Capture network and DER monitoring data through the use of the IEEE2030.5 standard.
- Provide network visibility using standards-based data definitions.
- Allow software algorithms and capabilities to be built using this standards-based data.

The evolve framework provides a software development environment in which both operational forecasts and operating envelopes can be calculated. Further details of the calculations processes are captured in the evolve Blueprint document, previously submitted as one of the evolve knowledge sharing reports.

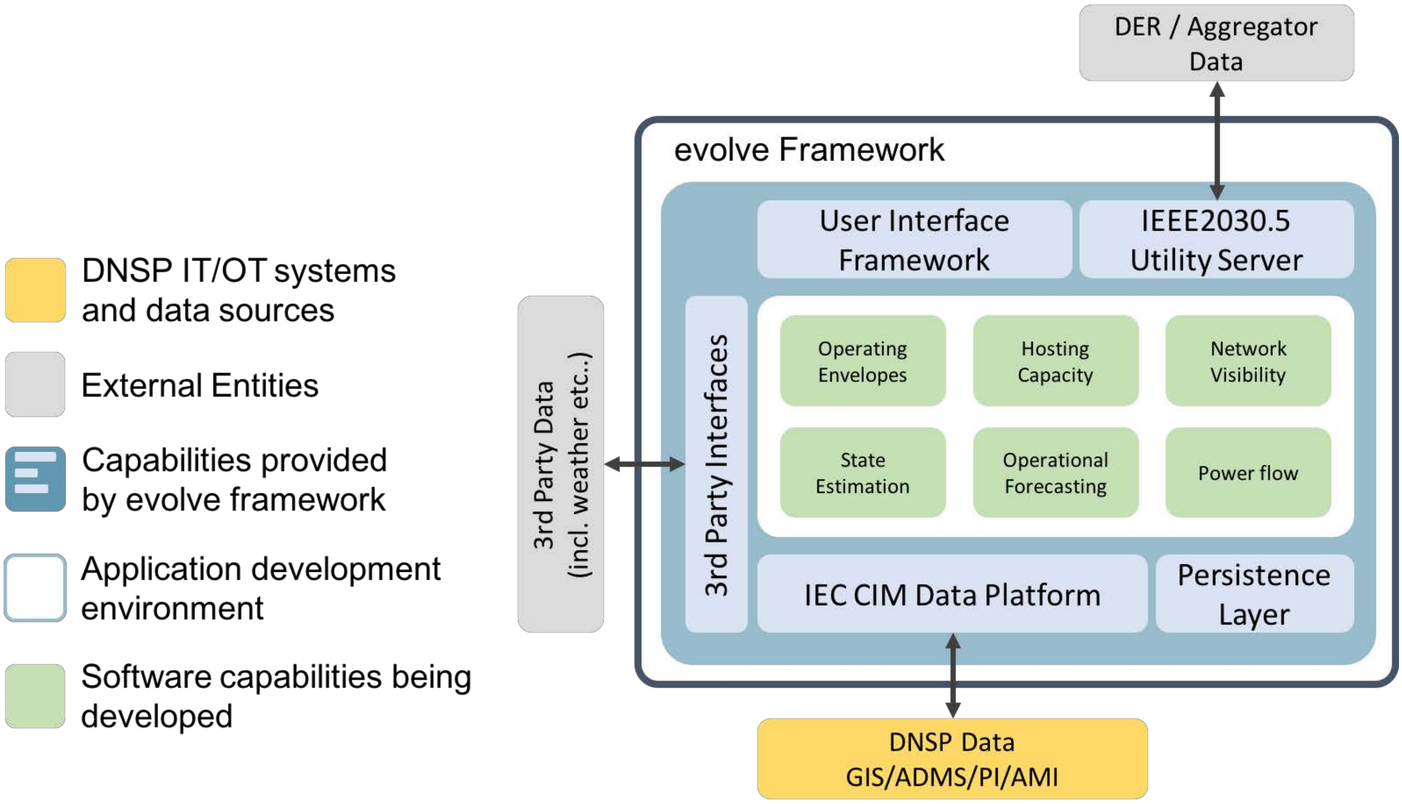

Figure 26. The evolve framework as it has been deployed to support the evolve project.

DER Devices, Optimisation and Control

At the nexus of many of the capabilities described in previous sections are the DER assets themselves and the systems that monitor, optimise and control these DER assets. While many of these local control systems are proprietary, they play a vital role in not only providing network visibility but also operationally enacting the operating envelopes. Future knowledge sharing reports will provide further details from the DER aggregator partners in the evolve project about the experiences of implementing operating envelopes within these local control systems.

Social License

Social license refers to the acceptance or approval of a concept, project or methodology by the local community and other stakeholders. While the evolve project was structured around the technical and technological capability development of operating envelopes, there is a broad appreciation that these capabilities will impact electricity customers and that it is imperative that these customers provide the social license to operate for the at scale deployment and adoption of dynamic operating envelopes. Future work to engage with customers and customer representatives to assess their understanding and provide feedback on the concept and implementation of operating envelopes will be undertaken, with results to be reported in future evolve knowledge sharing reports.

Rules and Regulations

While the evolve project was structured around the technical and technological capability development of operating envelopes, there is broad recognition that the use of these capabilities may require new rules and regulations. Through the evolve project and related initiatives, there is work underway to better understand and develop any new rules and regulations. The outcomes of these activities will be provided as an update in future evolve knowledge sharing reports.

9. Testing and Validation

Testing and validation of operating envelopes will commence in the second half of 2020 and the results will be reported in future knowledge sharing outputs of the evolve project.

10. Appendix

API Specification

Please find attached.

Evolve API (0.1.2)

Download OpenAPI specification: Download

License:

Authentication

registration

Aggregators are provided (out-of-band) a client ID and client secret in order to access the API. These are used within the OAuth 2.0 client credentials flow in order to retrieve an access token with the required scope. The example below (using curl) retrieves the access token with an expiry of 10 hours.

```
curl -X POST \
  http://<host>/o/token/ \
  -H 'Authorization: Basic <base64encoded(client_id:secret)' \
  -H 'Content-Type: application/x-www-form-urlencoded' \
  -d grant_type=client_credentials
```


```
{
    "access_token": "<access_token>",
    "expires_in": 36000,
    "token_type": "Bearer",
    "scope": "read write groups"
}
```


Subsequent requests can be made with the access token as authorization

```
curl -X GET \
  http://<host>/site/site_id/ \
  -H 'Authorization: Bearer <access_token>' \
  -H 'Content-Type: application/json' \
```

Security Scheme Type	OAuth2
clientCredentials OAuth Flow	**Token URL:** http://evolve.cecs.anu.edu.au/o/token/ **Scopes:** • `write` - register devices and write data • `read` - view device and site info

site

End points under the site namespace provide services relating to the registration of sites and devices. A site corresponds to a connection point (NMI), under which distributed energy resources (end devices) may be registered.

While end device information should align to the IEEE 2030.5 standard, the protocol used to communicate this information does not. As such, it is anticipated that these end points will change over time to align more closely with the standard.

Topological information (linking end devices to sites) is not in the scope of 2030.5 but will remain a core concept for this API.

List all available sites

AUTHORIZATIONS: registration (`read`)

Responses

— **200** Success

GET `/site/`

List all the devices for given site

AUTHORIZATIONS: registration (`read`)

PATH PARAMETERS

`siteID` required	string Site identifier (NMI)

Responses

— 200 Success

```
GET /site/{siteID}/
```

Register a new Site and Devices

AUTHORIZATIONS: registration (`write`)

PATH PARAMETERS

`siteID` required	string Site identifier (NMI)

REQUEST BODY SCHEMA: application/json

Site details

`siteID`	string

required	Site NMI
nPhases	integer Number of phases
endDeviceList ›	Array of objects (EndDevice)

Responses

— 200 successful operation

PUT /site/{siteID}/

Request samples

Payload

Content type

application/json

Copy Expand all Collapse all


```
{
    "siteID": "string",
    "nPhases": 0,
  - "endDeviceList": [
      + { … }
    ]
}
```

De-register the site from the aggregator

AUTHORIZATIONS: registration (`write`)

PATH PARAMETERS

`siteID` required	string NMI to deregister

Responses

— **400** Invalid ID supplied

DELETE `/site/{siteID}/`

Register one or more devices at the site using list of devices

AUTHORIZATIONS: registration (`write`)

REQUEST BODY SCHEMA: application/json

List of end devices to be created

`Array [`

`edevID` required	string Device identifier
`siteID`	string

Site ID of linked site. Note that this field is mandatory only when the siteID is not specified either in the URL string or when the device is not a component of a site in the request body.

`deviceCategory` required

integer
Device Category (as per 2030.5-2018 spec). Each bit is '1' if the category is supported by the device

Bit	Category
0	Programmable Communicating Thermostat
1	Strip Heaters
2	Baseboard Heaters
3	Water Heater
4	Pool Pump
5	Sauna
6	Hot Tub
7	Smart Appliance
8	Irrigation Pump
9	Managed Commercial and Industrial Loads
10	Simple Misc (Residential On/Off) Loads
11	Exterior Lighting
12	Interior Lighting
13	Load Control Switch
14	Energy Management System
15	Smart Energy Module
16	Electric Vehicle
17	EVSE
18	Virtual or Mixed DER
19	Reciprocating Engine
20	Fuel Cell

21	PV System
22	Combined Heat and Power
23	Combined PV and Storage
24	Other Generation System
25	Other Storage System

Example “0x800000” - Combined PV and Storage “0x200000” - PV System

`deviceReadingAccuracy` integer
Integer describing the accuracy of the device readings

`nPhases` integer
Number of phases for device (if applicable)

`rtgMaxChargeRateW` number
DERCapability::rtgMaxChargeRateW - the maximum rate (in W) at which the resource can charge.

`rtgMaxDischargeRateW` number
DERCapability::rtgMaxDischargeRateW - the maximum rate (in W) at which the resource can discharge.

`rtgMaxWh` number
DERCapability::rtgMaxWh - the maximum capacity (in Wh) of the resource.

]

Responses

— **200** Success

POST `/site/{siteID}/edev/`

Request samples

Payload

Content type
application/json

Copy Expand all Collapse all


```
[
  - {
        "edevID": "string",
        "siteID": "string",
        "deviceCategory": 0,
        "deviceReadingAccuracy": 0,
        "nPhases": 0,
        "rtgMaxChargeRateW": 0,
        "rtgMaxDischargeRateW": 0,
        "rtgMaxWh": 0
    }
]
```


Register a new end device at an existing site.

AUTHORIZATIONS: registration (`write`)

PATH PARAMETERS

`siteID` required	string NMI to which device is registered
`edevID` required	string Device identifier

REQUEST BODY SCHEMA: application/json

Device that needs to be added to the site

`edevID`

`required`

string
Device identifier

`siteID`

string
Site ID of linked site. Note that this field is mandatory only when the siteID is not specified either in the URL string or when the device is not a component of a site in the request body.

`deviceCategory` `required`

integer
Device Category (as per 2030.5-2018 spec). Each bit is '1' if the category is supported by the device

Bit	Category
0	Programmable Communicating Thermostat
1	Strip Heaters
2	Baseboard Heaters
3	Water Heater
4	Pool Pump
5	Sauna
6	Hot Tub
7	Smart Appliance
8	Irrigation Pump
9	Managed Commercial and Industrial Loads
10	Simple Misc (Residential On/Off) Loads
11	Exterior Lighting
12	Interior Lighting
13	Load Control Switch
14	Energy Management System
15	Smart Energy Module
16	Electric Vehicle
17	EVSE

18	Virtual or Mixed DER
19	Reciprocating Engine
20	Fuel Cell
21	PV System
22	Combined Heat and Power
23	Combined PV and Storage
24	Other Generation System
25	Other Storage System

Example “0x800000” - Combined PV and Storage “0x200000” - PV System

`deviceReadingAccuracy`	integer Integer describing the accuracy of the device readings
`nPhases`	integer Number of phases for device (if applicable)
`rtgMaxChargeRateW`	number DERCapability::rtgMaxChargeRateW - the maximum rate (in W) at which the resource can charge.
`rtgMaxDischargeRateW`	number DERCapability::rtgMaxDischargeRateW - the maximum rate (in W) at which the resource can discharge.
`rtgMaxWh`	number DERCapability::rtgMaxWh - the maximum capacity (in Wh) of the resource.

Responses

— **200** successful operation

PUT /site/{siteID}/edev/{edevID}/

Request samples

Payload

Content type

application/json

Copy Expand all Collapse all


```
{
    "edevID": "string",
    "siteID": "string",
    "deviceCategory": 0,
    "deviceReadingAccuracy": 0,
    "nPhases": 0,
    "rtgMaxChargeRateW": 0,
    "rtgMaxDischargeRateW": 0,
    "rtgMaxWh": 0
}
```

Delete the specified device on that site

AUTHORIZATIONS: registration (`write`)

PATH PARAMETERS

`siteID` required	string NMI to which device is registered
`edevID` required	string Serial Num of Device

Responses

— 200 successful operation

DELETE `/site/{siteID}/edev/{edevID}/`

edev

Device registration and monitoring

Post a list of one or more devices

AUTHORIZATIONS: registration (`write`)

REQUEST BODY SCHEMA: application/json

Device to be registered to a site

`Array [`

`edevID` required	string Device identifier
`siteID`	string Site ID of linked site. Note that this field is mandatory only when the siteID is not specified either in the URL string or when the device is not a component of a site in the request body.
`deviceCategory` required	integer Device Category (as per 2030.5-2018 spec). Each bit is '1' if the category is supported by the device

Bit	Category
0	Programmable Communicating Thermostat
1	Strip Heaters
2	Baseboard Heaters
3	Water Heater
4	Pool Pump
5	Sauna
6	Hot Tub
7	Smart Appliance
8	Irrigation Pump
9	Managed Commercial and Industrial Loads
10	Simple Misc (Residential On/Off) Loads
11	Exterior Lighting
12	Interior Lighting
13	Load Control Switch
14	Energy Management System

15	Smart Energy Module
16	Electric Vehicle
17	EVSE
18	Virtual or Mixed DER
19	Reciprocating Engine
20	Fuel Cell
21	PV System
22	Combined Heat and Power
23	Combined PV and Storage
24	Other Generation System
25	Other Storage System

Example “0x800000” - Combined PV and Storage “0x200000” - PV System

`deviceReadingAccuracy` integer
Integer describing the accuracy of the device readings

`nPhases` integer
Number of phases for device (if applicable)

`rtgMaxChargeRateW` number
DERCapability::rtgMaxChargeRateW - the maximum rate (in W) at which the resource can charge.

`rtgMaxDischargeRateW` number
DERCapability::rtgMaxDischargeRateW - the maximum rate (in W) at which the resource can discharge.

`rtgMaxWh` number
DERCapability::rtgMaxWh - the maximum capacity (in Wh) of the resource.

]

Responses

— **201** Device created

— **401** Unauthorized

POST /edev/

Request samples

Payload

Content type
application/json

Copy Expand all Collapse all


```
[
  - {
        "edevID": "string",
        "siteID": "string",
        "deviceCategory": 0,
        "deviceReadingAccuracy": 0,
        "nPhases": 0,
        "rtgMaxChargeRateW": 0,
        "rtgMaxDischargeRateW": 0,
        "rtgMaxWh": 0
    }
]
```

Get the attributes of the device

AUTHORIZATIONS: registration (`read`)

PATH PARAMETERS

`edevID` required	string Device identifier

Responses

— **200** successful operation

```
GET /edev/{edevID}/
```

Update the attributes of the device

AUTHORIZATIONS: registration (`write`)

PATH PARAMETERS

`edevID` required	string Device identifier

REQUEST BODY SCHEMA: application/json

Device that needs to be added to the site

`edevID`	string

required

Device identifier

siteID

string
Site ID of linked site. Note that this field is mandatory only when the siteID is not specified either in the URL string or when the device is not a component of a site in the request body.

deviceCategory
required

integer
Device Category (as per 2030.5-2018 spec). Each bit is '1' if the category is supported by the device

Bit	Category
0	Programmable Communicating Thermostat
1	Strip Heaters
2	Baseboard Heaters
3	Water Heater
4	Pool Pump
5	Sauna
6	Hot Tub
7	Smart Appliance
8	Irrigation Pump
9	Managed Commercial and Industrial Loads
10	Simple Misc (Residential On/Off) Loads
11	Exterior Lighting
12	Interior Lighting
13	Load Control Switch
14	Energy Management System
15	Smart Energy Module
16	Electric Vehicle
17	EVSE
18	Virtual or Mixed DER

19	Reciprocating Engine
20	Fuel Cell
21	PV System
22	Combined Heat and Power
23	Combined PV and Storage
24	Other Generation System
25	Other Storage System

Example “0x800000” - Combined PV and Storage “0x200000” - PV System

`deviceReadingAccuracy`	integer Integer describing the accuracy of the device readings
`nPhases`	integer Number of phases for device (if applicable)
`rtgMaxChargeRateW`	number DERCapability::rtgMaxChargeRateW - the maximum rate (in W) at which the resource can charge.
`rtgMaxDischargeRateW`	number DERCapability::rtgMaxDischargeRateW - the maximum rate (in W) at which the resource can discharge.
`rtgMaxWh`	number DERCapability::rtgMaxWh - the maximum capacity (in Wh) of the resource.

Responses

— **200** Successfully updated

PUT /edev/{edevID}/

Request samples

Payload

Content type

application/json

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```
{
    "edevID": "string",
    "siteID": "string",
    "deviceCategory": 0,
    "deviceReadingAccuracy": 0,
    "nPhases": 0,
    "rtgMaxChargeRateW": 0,
    "rtgMaxDischargeRateW": 0,
    "rtgMaxWh": 0
}
```


mup

Sending measurement data

Write a set of site and device measurements

AUTHORIZATIONS: registration (`write`)

PATH PARAMETERS

`siteID` required	string Site for which measurements were taken

REQUEST BODY SCHEMA: application/json

Site and device measurements object

`siteID` required	string
`measurements` ›	Array of objects (Measurement)
`endDeviceList` ›	Array of objects

Responses

— 200 Success

POST /mup/site/{siteID}/

Request samples

Payload

Content type

application/json

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```
{
    "siteID": "string",
  - "measurements": [
      + { … }
    ],
  - "endDeviceList": [
      + { … }
    ]
```

```
}
```

envelopes

Endpoints under this namespace serve operating envelopes at a site-by-site level. There are two types of operating envelope schemas based on varied control schemes or modes. These can be used interchangeably for a given timeslot. The two control modes are:

1. RealPower (RP): This mode applies simple real power constraints for import and export, regardless of the value of reactive power.
2. ApparentPower (AP): This mode expands on the RP mode definition with an additional reactive power support ratio, which determines the reactive power required in order to import or export beyond the active power constraint. This allows a system with controllable power factor to compensate for increased import or export by adjusting the system reactive power. An additional parameter, the apparent power constraint, limits the extent to which reactive power support can be used to increase the power transfer at the site.

NB. All power values are defined in Watts, and use load convention (negative indicating export).

List all operating envelopes for the specified site

AUTHORIZATIONS: registration (`read`)

PATH PARAMETERS

`siteID` required	string Site for which measurements were taken

REQUEST BODY SCHEMA: application/json

Operating envelopes object

`Array [`

`start` required	integer Start DateTime for the operating envelope in Unix time with second precision.
`duration` required	integer Duration of the operating envelope in seconds.
`phase` required	string Target phase for the operating envelope.
`mode` required	string Enum: `"RP"` `"AP"` The control mode of the given operating envelope.
`published_at` required	integer The Unix timestamp (second precision) when the operating envelope was published.
`importActivePowerLimit`	number A RP mode property. This is the maximum real power value that the given site can import.
`exportActivePowerLimit`	number A RP mode property. This is the maximum real power value that the given site can export.
`importActivePowerConstraint`	number An AP mode property. This is the constraint on the imported real power with no power factor adjustment.
`exportActivePowerConstraint`	number An AP mode property. This is the constraint on the exported real power with no power factor adjustment.
`importReactivePowerSupportRatio`	number An AP mode property. Ratio of the allowable change in imported real power beyond the importActivePowerConstraint that a unit change in reactive power can support.
`exportReactivePowerSupportRatio`	number An AP mode property. Ratio of the allowable change in exported real power beyond the

	exportActivePowerConstraint that a unit change in reactive power can support.
`importApparentPowerLimit`	number An AP mode property. This is the maximum apparent power value that the given site can import.
`exportApparentPowerLimit`	number An AP mode property. This is the maximum apparent power value that the given site can export.

]

Responses

— **200** Success

GET /envelopes/{siteID}

Request samples

Payload

Content type
application/json

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[

```
- {
    "start": 0,
    "duration": 0,
    "phase": "string",
    "mode": "RP",
    "published_at": 0,
    "importActivePowerLimit": 0,
    "exportActivePowerLimit": 0,
    "importActivePowerConstraint": 0,
    "exportActivePowerConstraint": 0,
    "importReactivePowerSupportRatio": 0,
    "exportReactivePowerSupportRatio": 0,
    "importApparentPowerLimit": 0,
    "exportApparentPowerLimit": 0
  }
]
```