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Summary

This paper proposes a methodology for calculating dynamic operating envelopes that can be used with limited network model data or telemetry requirements. This method is designed for simplicity and efficiency. It can serve as a backup option when more sophisticated optimisation techniques are either unavailable, impractical, or offer no additional benefit over more advanced but more computationally expensive methods.

It is designed to be simpler to implement, thus allowing more customers to access dynamic connections sooner, whilst still providing improvements in hosting capacity over static limits.

Keywords

Dynamic Operating Envelopes (DOE), Distributed Energy Resource (DER), DERMS (Distributed Energy Resource Management System)

Operating Envelopes

Operating envelopes are the operational limits within which distributed energy resources (DER) can import and export electricity, based on the physical constraints of the local network [1]. Historically, operating envelopes have been provided as fixed limits based on the capacity of the network. As they are static, they must allow for worst-case conditions into the future.

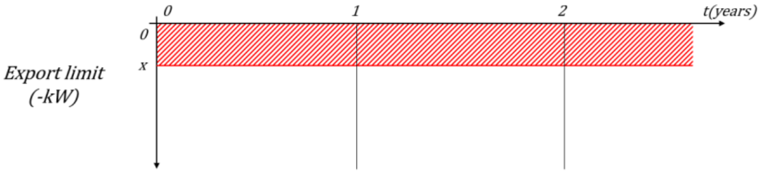

Figure 1: Static Export Limit

Dynamic operating envelopes (DOE) are import and export limits that can vary over time and location. Dynamic export limits can enable higher levels of energy exports from customers' solar photovoltaic (PV) and battery energy storage systems (BESS) by allowing higher export limits when there is more hosting capacity on the local network. Dynamic import limits provide a more granular way of responding to times of maximum demand for flexible loads like BESS and electric vehicle (EV) chargers. While unmanaged loads such as appliances and cooking equipment may still exceed a dynamic import limit, the managed loads may only consume while the import limit is not exceeded.

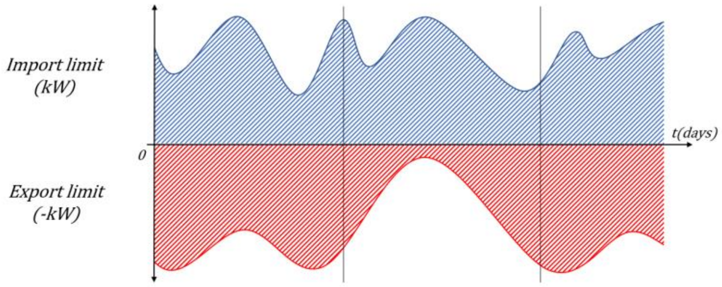

Figure 2: Dynamic Operating Envelope (DOE)

Communication Mechanism

IEEE 2030.5 Smart Energy Profile (SEP2) [3], is a communications standard used to communicate a DOE to the customer installation. The Common Smart Inverter Profile – Australia (CSIP-AUS) [4] is the Australian profile for how the SEP2 standard should be applied in the Australian context, with specific jurisdictional implementations provided in each DNSP's implementation handbook [5]. The SEP2 Utility Server is a module of the DER Management System (DERMS) for communicating with DER.

Consumer Perspective

The Distributed Energy Integration Program (DEIP) identified five themes for capacity allocation with strong support in the Consumer Perspectives Workshop [2]:

- should be based on clear, consistent, and transparent principles
- should factor in the installed capacity at the customer premises
- principles should be simple to explain to the general public
- could have a fixed and a variable component (widely but not universally supported)
- should be based on net exports rather than total generation

This paper and the documented approach to DOE is informed by these principles.

Calculation Methodologies

Depending on the availability of telemetry and network model data on a given feeder, various methodologies for calculating DOEs can be employed. Due to their dynamic, near-real-time nature, the optimality of envelopes needs to be balanced with calculation complexity, network model and grid visibility requirements, to ensure that they can be calculated in a timely and scalable manner. [6] A fallback methodology is also required for cases where telemetry becomes unavailable.

This paper proposes two "Basic" methodologies that apply when more advanced methodologies are not available or required. Whilst various examples and indicative values are provided in this paper, it does not represent a standard or policy of Ergon Energy Network and Energex. This paper is intended to be used as a primer for other networks looking to develop similar methodologies. It is expected that it will be refined through iterative improvements and the actual methodology used on real networks will vary from those presented in this paper.

Basic DOE (without telemetry)

For a transformer with no transformer monitoring, a dynamic envelope can be calculated in a comparable way to how static limits were calculated historically. The major advantages of this over a static limit is that seasonal and time-of-day assumptions can be applied instead of always assuming worst-case conditions. Additionally, accommodations do not need to be made for future connection applications as assumptions can be updated as the network changes or as new DER is connected.

Basic DOE (with telemetry)

For a transformer with transformer monitoring, a dynamic envelope can be calculated by comparing the measured power flows through the transformer with the relevant network constraint to determine the additional capacity headroom available.

Advanced DOE

If enough transformers on a given feeder have telemetry, then Distribution System State Estimation (DSSE) [6] can be used to accurately estimate the power flows and voltages for all points on a feeder. This 'synthetic' telemetry can then be used in place of actual measurements, allowing for advanced capacity constrained optimisation to be used when determining the optimal envelope to assign to each connection on a feeder. Such 'advanced' methodologies are not the focus of this paper.

Envelope Inheritance

The intention of CSIP-AUS is to calculate an operating envelope per customer connection point. However, Distribution Network Service Providers (DNSPs) need to calculate various upstream envelopes that will contain the child envelopes so that upstream constraints are considered. For a Basic DOE, this will include distribution substation and feeder level envelopes, but for an advanced DOE this could include envelopes for each branch of a feeder.

To reduce complexity, any higher level of constraint will be passed through as an operational constraint when calculating downstream elements. For example, if a feeder constraint is present this can be factored in by de-rating all the downstream transformers by an appropriate amount.

Constraints

Contractual Constraint

The first constraint to consider when allocating a connection point operating envelope is the approved range of the connection agreements for any individual connection point. Different connections will have different constraints on how their envelope can be varied. For example, a three-phase connection is likely to be provided a higher upper limit than a single-phase connection (e.g. 30 kW instead of 10 kW) [7].

Thermal Constraint

The main network constraint that Basic DOEs are intended to address is the thermal nameplate rating of the distribution transformer. Due to the thermal inertia of oil, transformers can exceed the nameplate rating for short periods of time. This allows over-allocation of envelopes for short periods; however, an upper limit is still required for situations in which there is a large instantaneous change in load or generation. For example, due to sudden temperature change or cloud front. The allocated envelope should therefore never exceed the upper limit (e.g., 150% of nameplate) regardless of the operational capacity available.

For example, if a 100 kW rated transformer has 75 kW of generation (reverse-flow) and the constraint was set to allocate up to 100% of the transformer rating in each direction, there would be 175 kW of additional import capacity and 25 kW of export capacity available. However, only up to 150 kW of import capacity would be issued to avoid scenarios where the generation suddenly disappears (eg. due to a cloud passing over) as there is potential for the nameplate to be significantly overloaded in the short term until the operating envelope adjusts.

Generation Capacity Constraint

To prevent excessive loading on distribution transformers in case of inverter misconfiguration or maloperation, the connections process will limit the maximum aggregate installed inverter capacity (e.g. 200% of transformer's nameplate).

Voltage Constraint

As voltages can change rapidly and DOEs could have significant delays in responding to network changes, they are not intended as the primary mechanism for rectifying voltage constraints. Inverters will still be required to follow the autonomous voltage response modes outlined in AS/NZS 4777.2:2020 [8] to implement volt–var (from 240 V) and volt-watt (from 253 V) responding within 10 seconds and disconnect if the average voltage exceeds 258 V for ten minutes or 265 V for one second.

However, to reduce the occurrence of voltage non-compliance, inverters tripping on over-voltage and to share mitigation burden, DOEs should be responsive to observed network voltage. To achieve this, the DOE will reduce if network voltages are outside the desired range for that network (e.g. 216-253 V).

Upstream Constraints

Upstream constraints such as feeder ratings should be cascaded down through envelope inheritance to downstream networks.

Protection Constraint

Operational constraints should be set to prevent protection operation due to exceeding overcurrent limits. This applies to both local (transformer fuse) and upstream (recloser setting) constraints.

Assumptions

Any telemetry measured within the prior 15 minutes of a DOE's start time is considered a valid measurement. If telemetry values are stale, the transformer is treated as if it has no telemetry. Likewise, bad data (outside of some expected range) should also be discarded.

Where no telemetry is available, some worst-case assumptions can be made about how much export and import installed DER is contributing on the network to estimate a worst-case transformer power flow at a given time-of-day. Note that the below numbers are indicative only and assume that DER are predominantly solar PV. The assumptions may not represent the actual values used to calculate power flows in a production system.

For export limit calculations, assume:

- No self-consumption on systems without export limits
- Installed DER capacity is exporting at:
  - 100% max approved export from 10:00 to 14:00
  - 80% max approved export from 08:00 to 10:00 and 14:00 to 16:00
  - 0% max approved export all other times

If upstream telemetry is available for the feeder or zone substation power transformer and there are no reverse flows, it is assumed downstream DER are not exporting at full capacity. In this situation, assume:

- Installed DER capacity is exporting at:
  - 50% max approved export from 08:00 to 16:00 (whilst feeder is not reverse)
  - 0% max approved export all other times

For import limit calculations, assume:

- Estimated load is calculated based on the following
  - From 16:00 to 20:00: 120% of Transformer rating
  - From 10:00 to 14:00 (or whilst feeder reverse): 40% of rating
  - All other times: 75% of Transformer rating

Rate Limiting

The calculated DOE at the transformer level should be rate-limited so the published DOE values do not change too rapidly. This is to minimise the impact of the envelope 'hunting' and causing oscillations. It is suggested as an initial rule-of-thumb that envelopes don't increase by more than +20% of the transformer rating every 5 minutes. As alleviating a constraint and returning to zero is more important (and less likely to oscillate), we can decrease at a faster rate (e.g. 40% every 5 minutes).

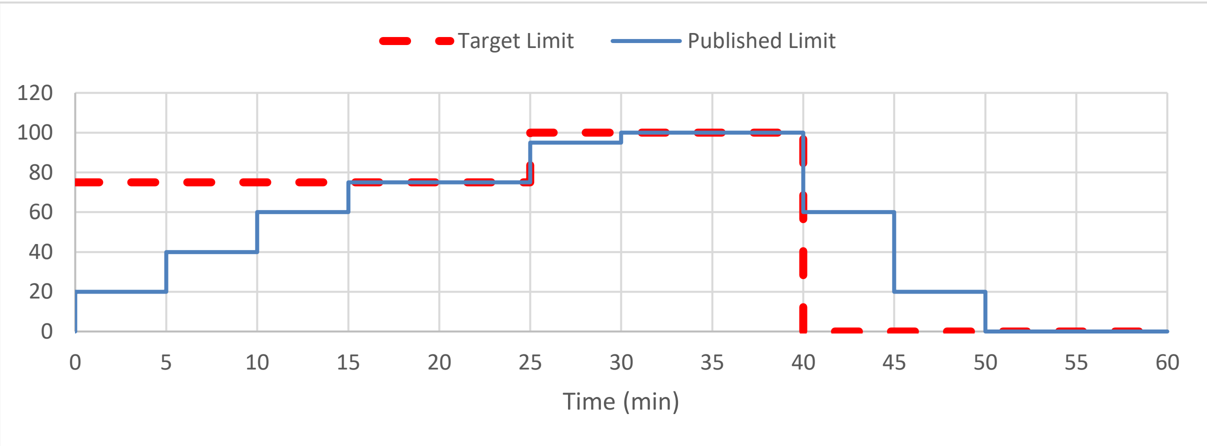

Figure 3: Example of Rate Limiting of DOE Basic Methodology

Connection Point Allocation

The program issued to all connection points on a low voltage (LV) network will be equally assigned to customers up to the maximum allowed limit for each connection. This is an iterative process; however, connection points will all first be allocated their minimum approved capacity.

The proposed methodology is intended to ensure some measure of 'fairness' for customers without introducing too much complexity. The optimal mechanism for allocation of envelopes will likely be explored further in future analysis.

The proposed methodology is referred to as an 'equal allocation'. One alternative approach for allocating DOE without an LV model is a 'proportional allocation' [8] where envelopes are allocated in proportion to the generation capacity behind each connection point. While avoiding the iterative process necessary for equal allocation, proportional allocation often results in a higher number of systems being curtailed and less burden placed on larger systems. For example, compare the 100 kW columns in Table 1 (highlighted). Neither the equal nor proportional allocation methodologies require an LV model, so the distance from the transformer does not influence the allocation. While simple to implement, such approaches may result in higher voltages and/or more curtailment than more optimised solutions that account for network impedance.

Table 1: Example LV DOE Export for Connection Points on a Distribution Transformer

Connection	Approved Export	Equal Allocation			Proportional Allocation (alternative)		
		50 kW Avail.	100 kW Avail.	200 kW Avail.	50 kW Avail.	100 kW Avail.	200 kW Avail.
CP-A (Fixed Legacy)	5.0 -> 5.0 kW	5.0 kW	5.0 kW	5.0 kW	5.0 kW	5.0 kW	5.0 kW
CP-B (Fixed)	1.5 -> 1.5 kW	1.5 kW	1.5 kW	1.5 kW	1.5 kW	1.5 kW	1.5 kW
CP-C (1PH)	1.5 -> 10.0 kW	7.3 kW	10.0 kW	10.0 kW	3.9 kW	7.4 kW	10.0 kW
CP-D (1PH)	1.5 -> 10.0 kW	7.3 kW	10.0 kW	10.0 kW	3.9 kW	7.4 kW	10.0 kW
CP-E (1PH)	1.5 -> 10.0 kW	7.3 kW	10.0 kW	10.0 kW	3.9 kW	7.4 kW	10.0 kW
CP-F (2PH)	1.5 -> 20.0 kW	7.3 kW	20.0 kW	20.0 kW	6.8 kW	14.4 kW	20.0 kW
CP-G (3PH)	1.5 -> 30.0 kW	7.3 kW	21.8 kW	30.0 kW	9.6 kW	21.4 kW	30.0 kW
CP-H (>30)	1.5 -> 50.0 kW	7.3 kW	21.8 kW	50.0 kW	15.3 kW	35.4 kW	50.0 kW
Total	**15.5 -> 136.5 kW**	**50.0 kW**	**100.0 kW**	**136.5 kW**	**50.0 kW**	**100.0 kW**	**136.5 kW**

Distribution Transformer

The transformer operating envelopes will be calculated based on the power flows through the transformer (either measured or assumed depending on available telemetry) to calculate the additional envelope available for the specified constraints.

Where telemetry is not available, assumptions must be made of the potential power flows which may result in constraints at certain times of day. As worst-case conditions must be considered, different expected loads will be calculated for the import and export calculations. For low DER penetrations, even this conservative approach will result in minimal time with export constraint. Due to the lack of telemetry, dynamically controlled loads will be constrained during peak load periods.

An example daily profile has been simulated in Figure 4. Due to the initial starting conditions, there is an initial ramp up period visible in the envelope.

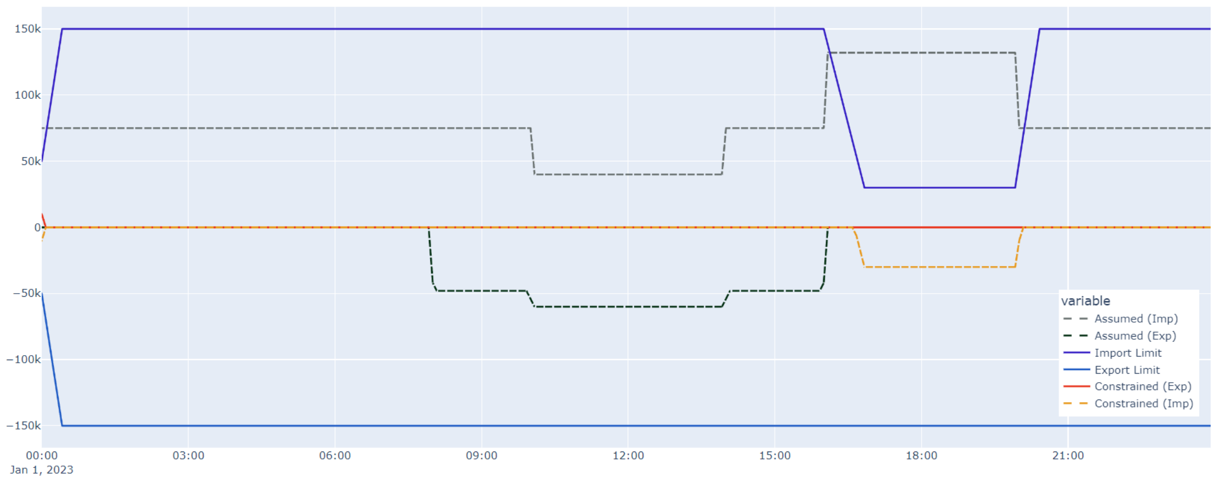

Figure 4: Example (no telemetry) 100 kW Tx with 30-60 kW DER capacity

As DER penetration increases, envelopes will eventually become constrained at certain times of day, as seen in Figure 5.

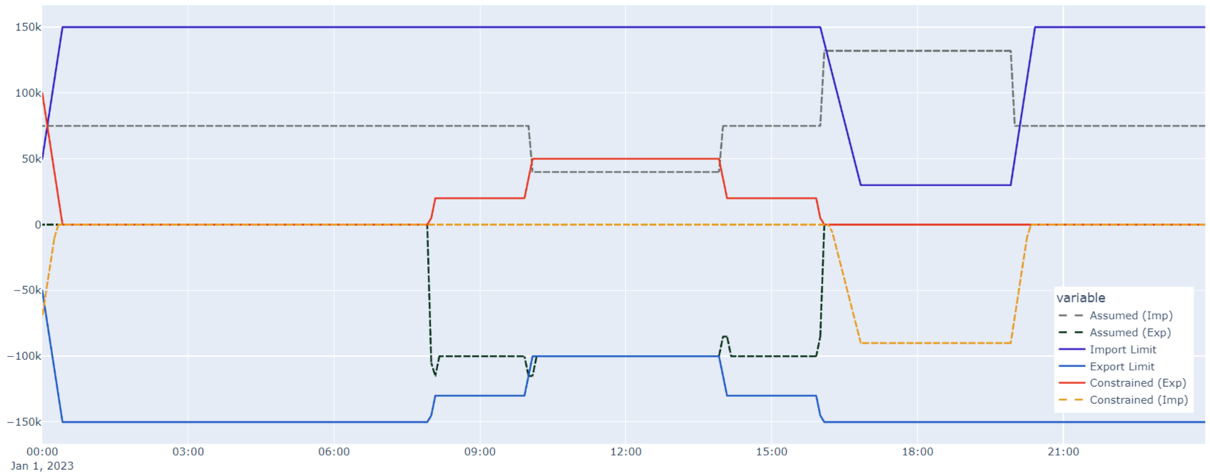

Figure 5: Example (no telemetry) 100 kW Tx with 30-150 kW DER capacity

If the feeder has telemetry and is not running negative, less conservative assumptions about the measured export can be made, which will result in a shorter duration of constraint.

If a Transformer Monitor was to be installed on the transformer, this would further reduce the amount of time constrained, even on a worst-case day like the simulation shown in Figure 6. This example also highlights the impact of over-allocating (in this case 150%), as the published limits fall back to the actual constraints (100% export and 120% import) once the measured power flow reaches these thresholds.

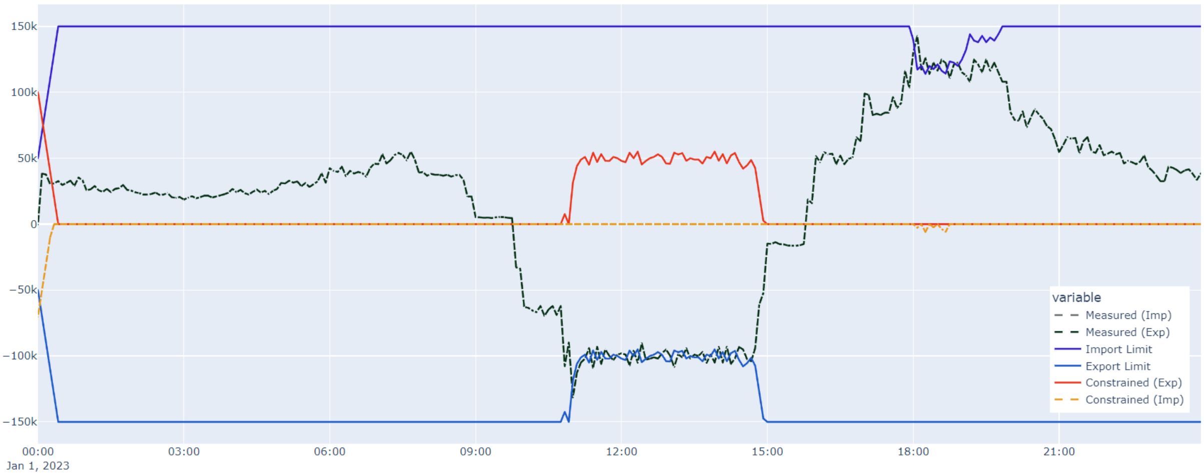

Figure 6: Example (with telemetry) 100 kW Tx with 30-150 kW DER capacity

If telemetry becomes unavailable, the calculation will fall back to assumed values for the power flow until recent telemetry is available again, which can be seen in an example with patchy telemetry in Figure 7.

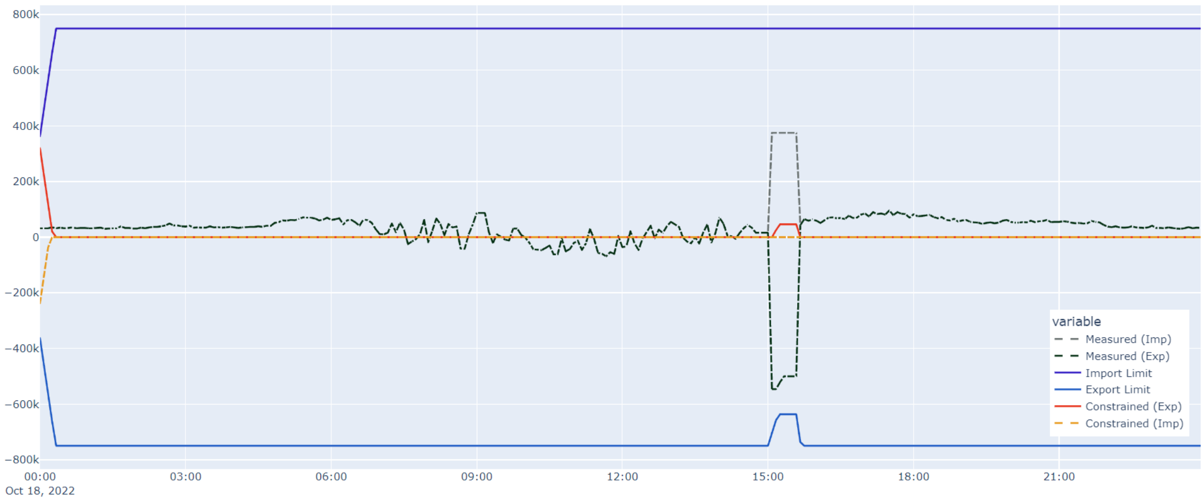

Figure 7: Example (with patchy telemetry) 500 kW Tx with 263-683 kW DER capacity

Distribution Feeder Level

A distribution feeder level envelope should be calculated based on the measured (or assumed) power flow of the feeder and the rating of the feeder. It is worth noting that feeder ratings can vary by season or time of day and may also be used to cascade down upstream system constraints as well.

Where a feeder constraint is present, the available envelope should be apportioned as downstream transformer operational constraints, relative to the installed capacity of DER on each transformer. A simple example is, a feeder export constraint of 1,200 kVA with three transformers (with 400 kVA, 400 kVA and 600 kVA of installed DER) would each be issued with an operational rating of 400 kVA in a similar manner to the connection point allocation.

Requirement for Export Constraint

For transformers without telemetry, the Basic methodology with the assumptions outlined above does not apply an export constraint until DER penetration reaches 100% of the transformer rating, assuming no other constraints are present. At current PV penetrations (Table 2) this would result in a constraint being applied for only 1.7% of transformers, although this number will increase as more DER is installed. For those constrained transformers with a dedicated customer (0.3%), telemetry will be sent back from the customer, providing sufficient visibility to allow them to operate up to the network constraint level. Of the remaining 1.4% that would be constrained, 21% of transformers have existing transformer monitoring.

Table 2: Installed inverter capacity as a percentage transformer rating

	No PV	*0-75%*	*75-100%*	*100%+*
1 customer	26.6%	10.0%	0.4%	0.3%
2-25 customers	22.7%	20.1%	1.2%	1.0%
25+ customers	0.7%	15.4%	1.2%	0.4%
Total	*50.1%*	*45.5%*	*2.8%*	*1.7%*

It should be noted that other network constraints (such as over-voltage) may still result in a reduced envelope at some times, and that local autonomous grid support functions may prevent an individual DER from achieving the published operating limit.

Conclusion

The proposed Basic methodology provides a simple mechanism for generating DOEs with limited network model data or telemetry whilst still providing better customer outcomes than traditional static limits. This can be used to support dynamic connections either as a fallback mechanism, or for sites with poor data or low DER penetration.

For networks that use this methodology, it is likely to require less compute than more advanced methodologies. Therefore, it is likely to be a cost-effective starting point when onboarding new customers. Networks that are still constrained frequently under this methodology, would then become candidates for an 'Advanced DOE' calculation methodology or installation of transformer monitoring where telemetry does not already exist. If persistent constraints still exist even for advanced methodologies, traditional network augmentation may be required.

This Basic methodology will act as a baseline for DOE calculation as customers sign up for dynamic connections, but it is likely to require iterative improvements as system performance is analysed. The assumptions made in this paper are likely to need reassessment as DER penetration increases and load trends change. In particular, the calculation of the import component for loads will need further development as EV charging becomes more widespread. It could be further improved by using representative load profiles instead of time-of-day assumptions based on categorisations such as LV network taxonomy, customer demographics, regional location, or seasons.

While further work is required, the proposed methodology will allow networks to offer the benefits of dynamic connections to all customers, regardless of where they connect on the network.

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