



**Model-free Dynamic Hosting
Capacity & Operating Envelopes**

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Agenda

Model Free Dynamic Operating Envelopes

1. Gridsight Overview
2. Australian DER Landscape
3. Solution Overview
4. Traditional Modelling Approach
5. Model Free
6. DOE Simulations
7. Real-Time Calculations
8. Future Work

Gridsight Overview

Network Analytics and Hosting Capacity Management

Dynamic Operating Envelopes



DER Detection & Compliance



Voltage Performance (incl. CVR design)



Identify Broken Neutrals



Transformer Loading & Connections



Customer to Transformer Mapping



Phase Identification

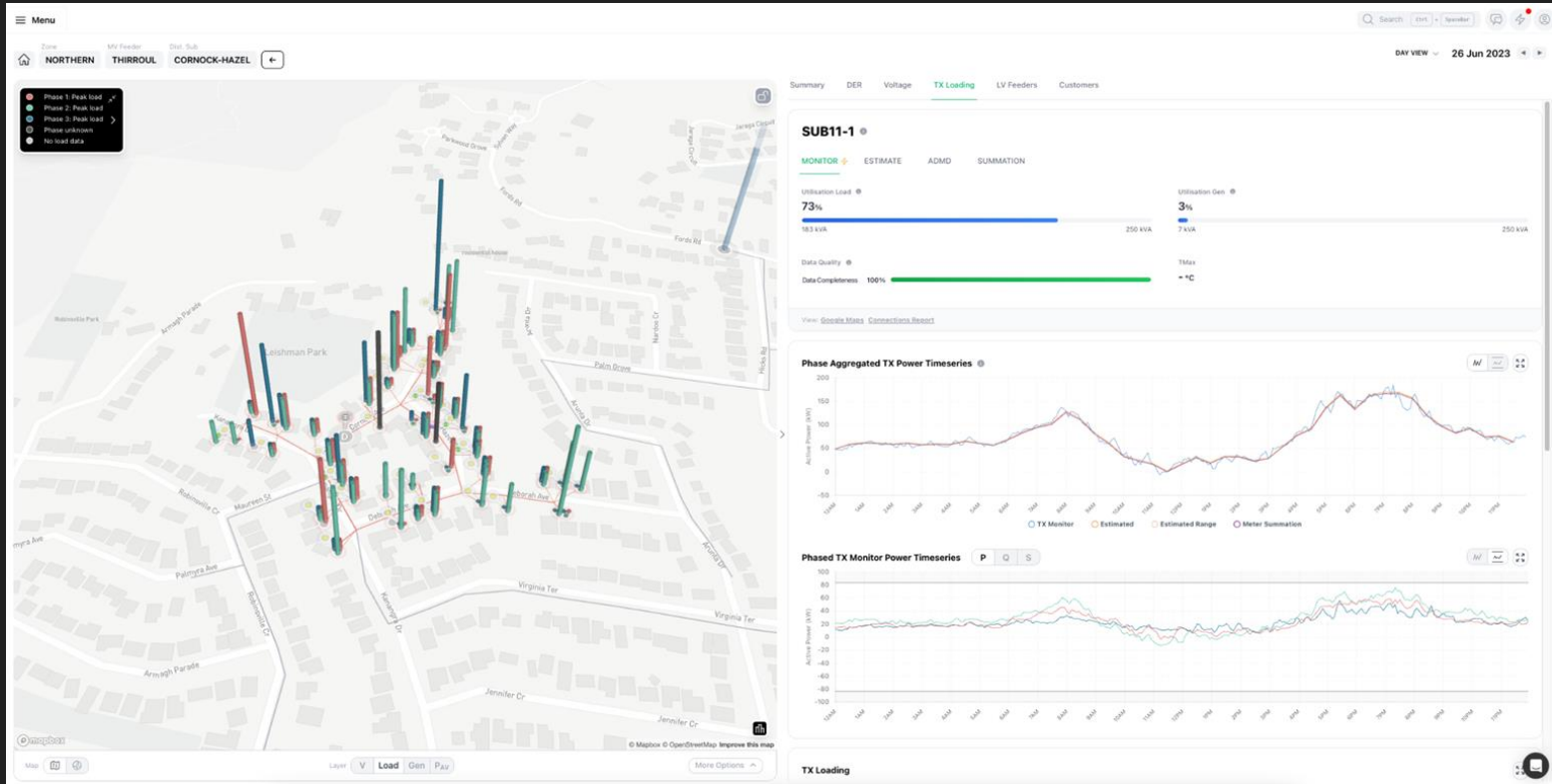


DER Connections



Gridsight Overview

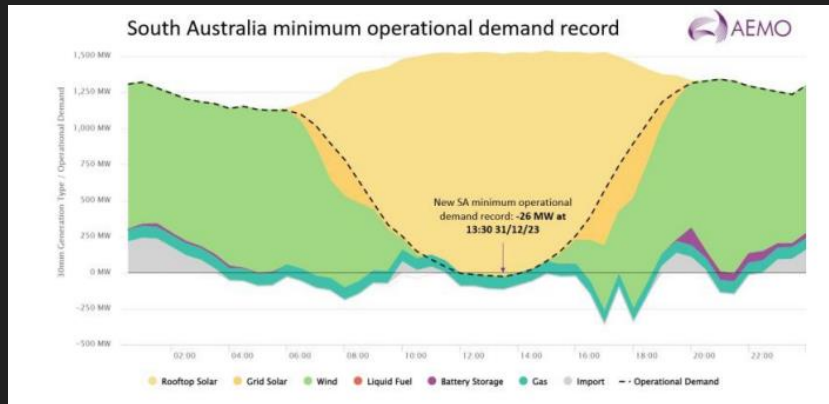
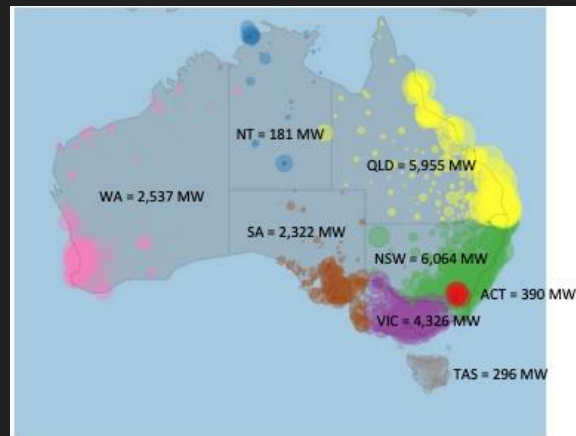
Network Analytics and Hosting Capacity Management



Australian DER Landscape

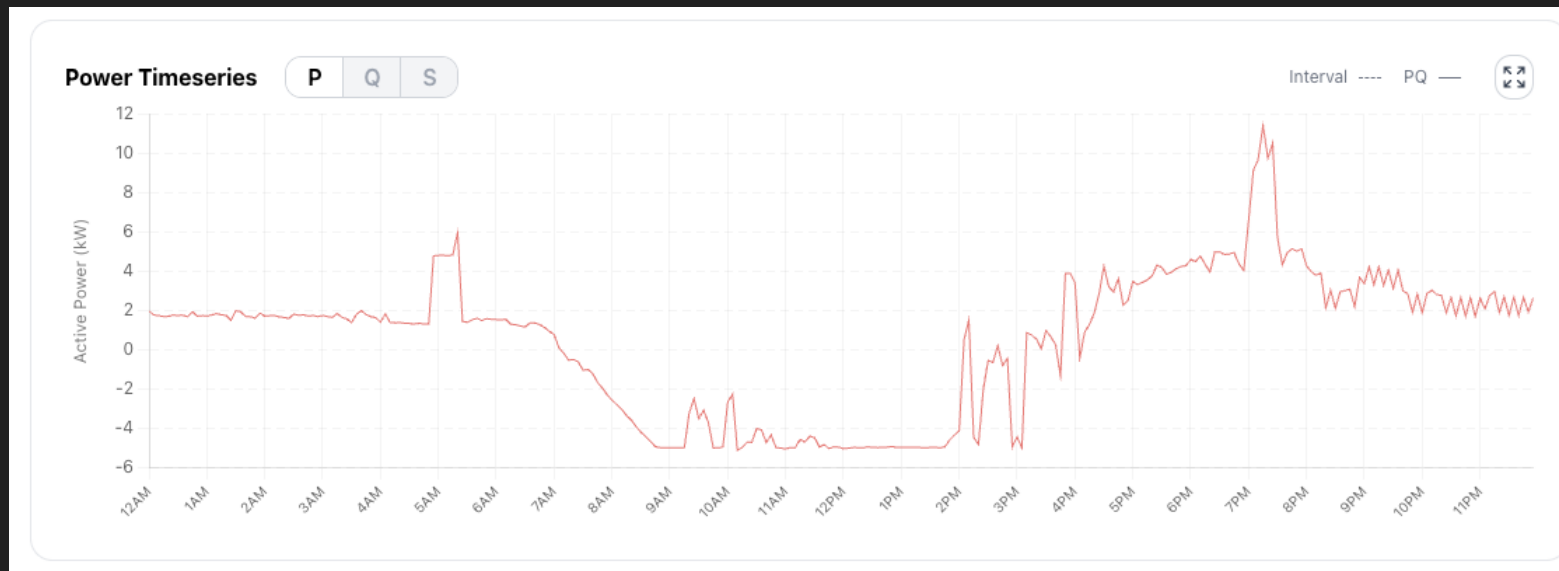
Rooftop Solar PV - Challenges

- ~20 GW installed capacity
- 1/3 Aus homes have solar
 - 1/2 homes in SA in QLD
- Entire state of SA recently powered entirely by solar, exporting back to NEM
- Excess solar causing constraints
 - Voltage
 - Thermal
 - System



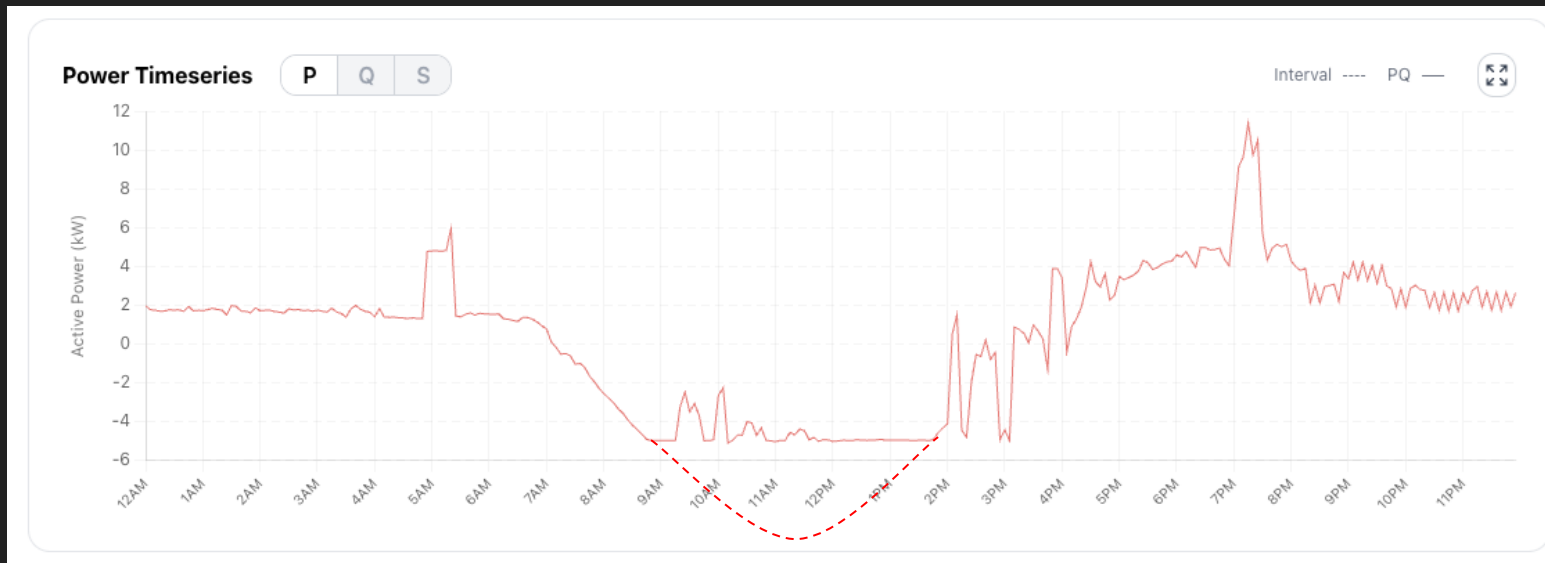
Australian DER Landscape

Rooftop Solar PV - Existing Solution: Static Export Limits



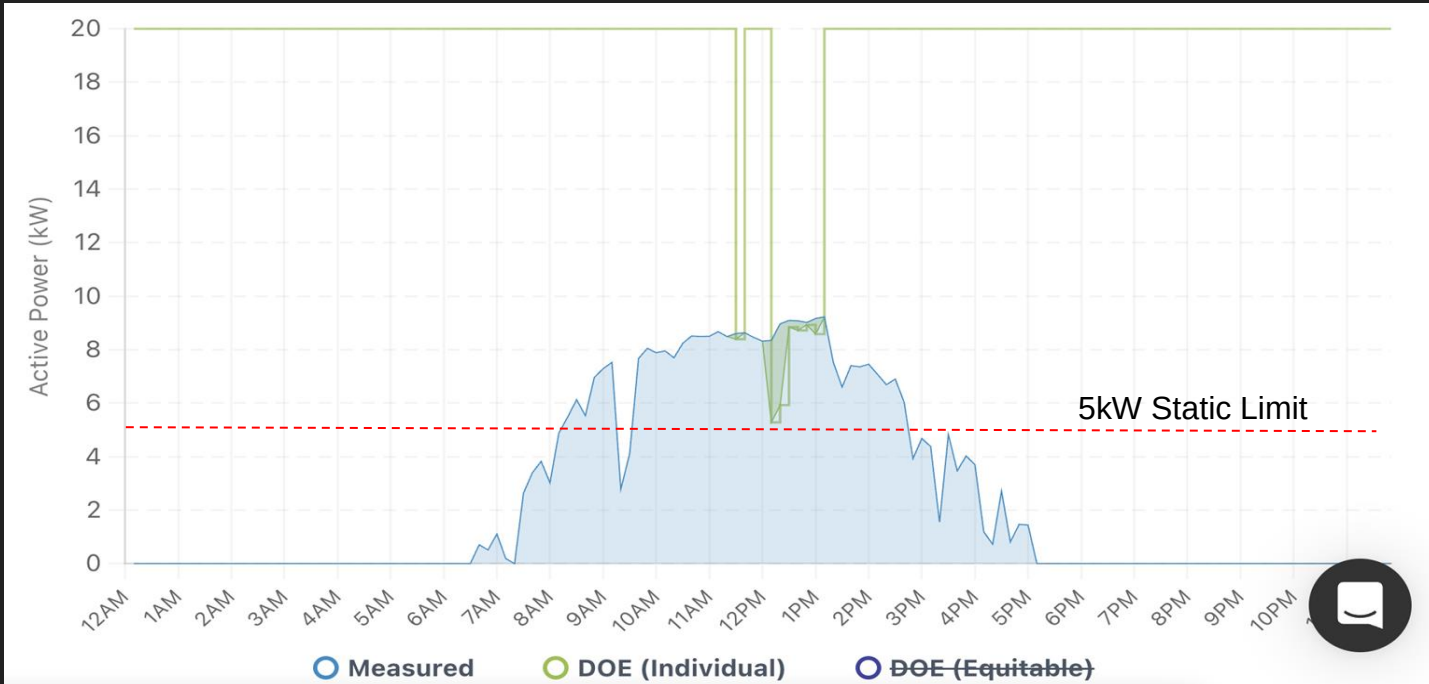
Australian DER Landscape

Rooftop Solar PV - Existing Solution: Static Export Limits



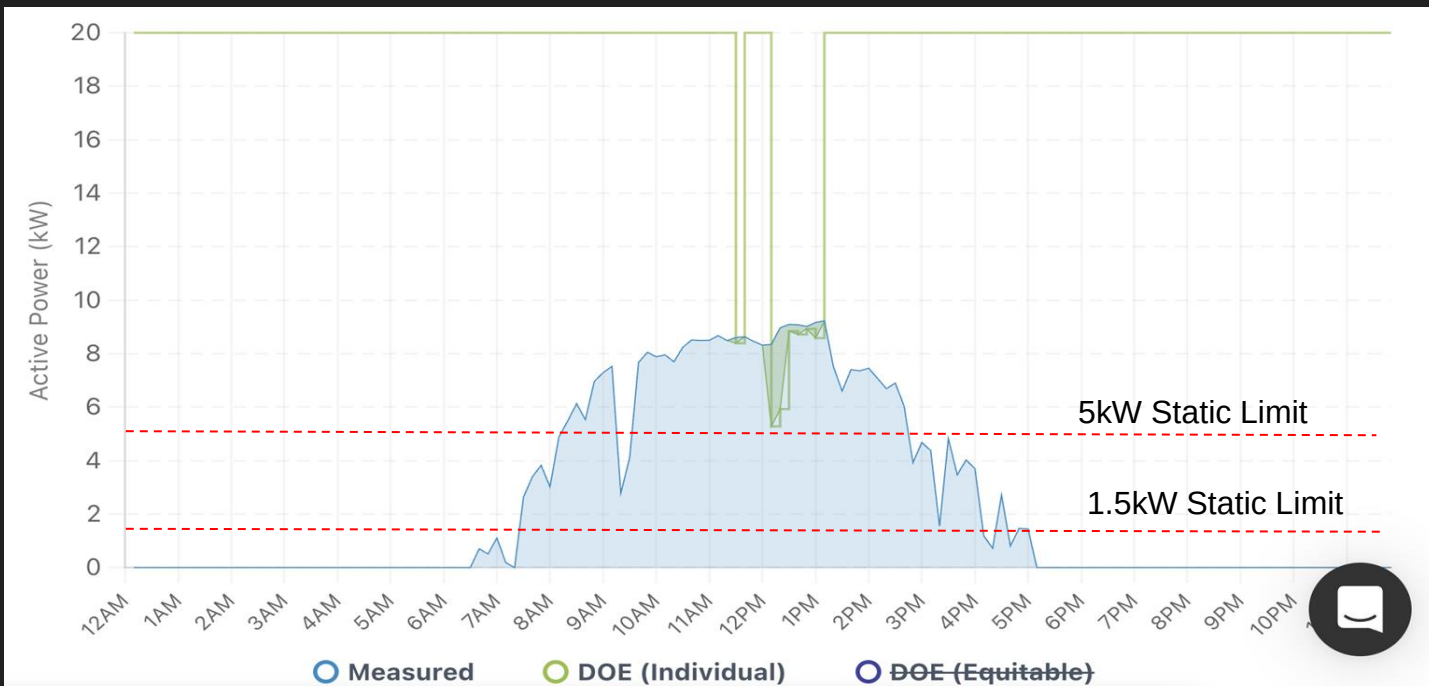
Australian DER Landscape

Rooftop Solar PV - Future Solution: Dynamic Operating Envelopes (DOE)



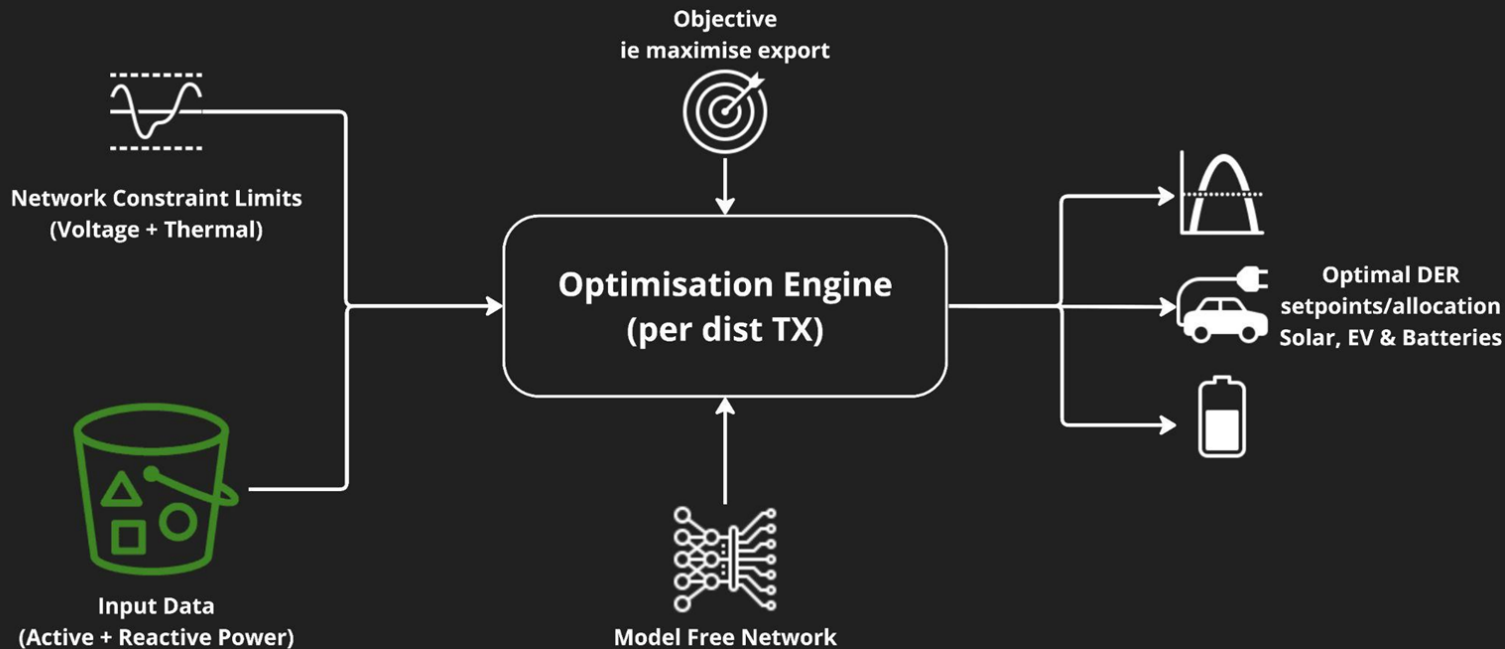
Australian DER Landscape

Rooftop Solar PV - Future Solution: Dynamic Operating Envelopes (DOE)

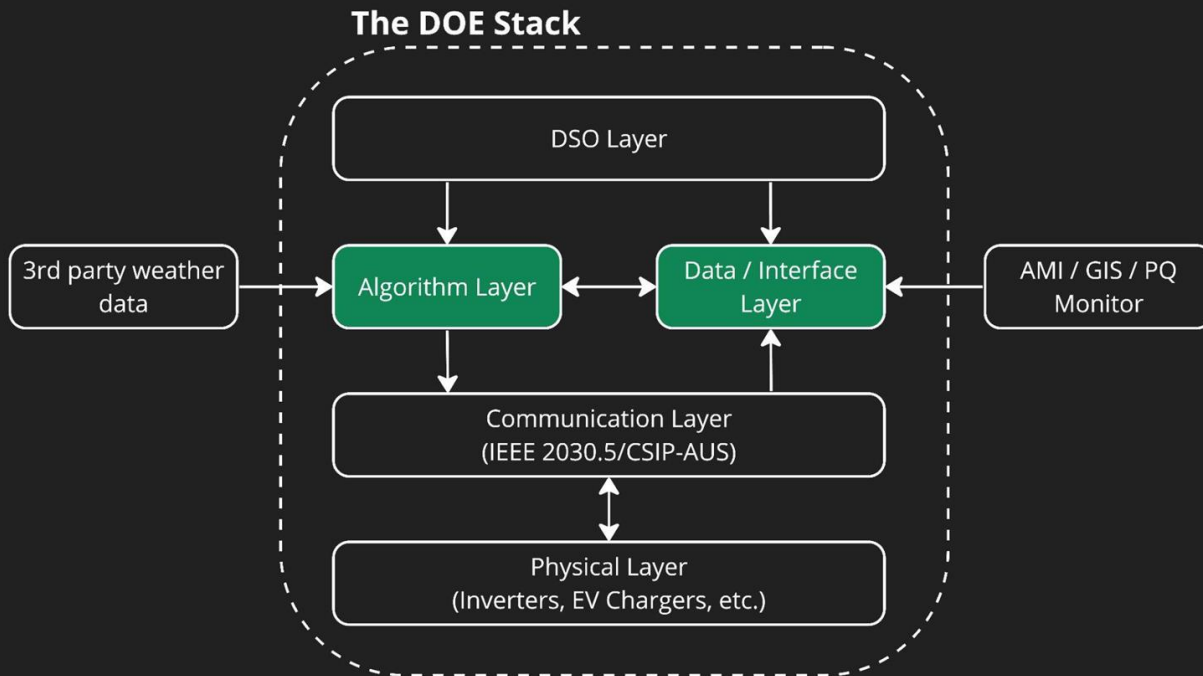


Solution Overview

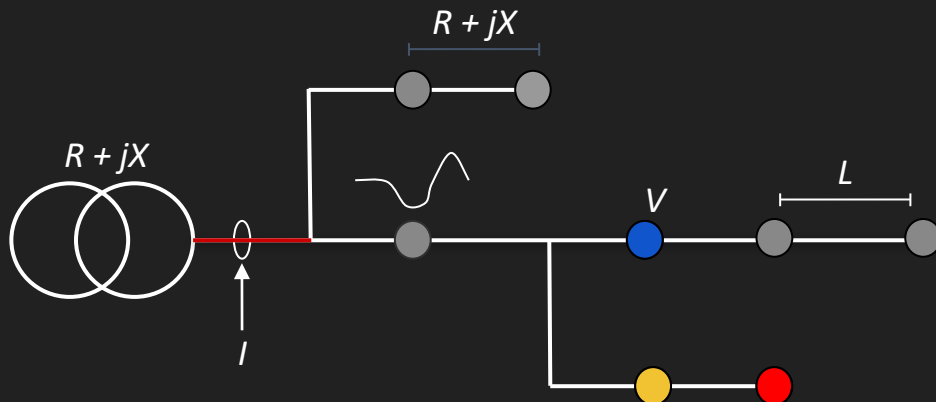
Model Free Optimal Powerflow



Solution Overview



Traditional Modelling Approach



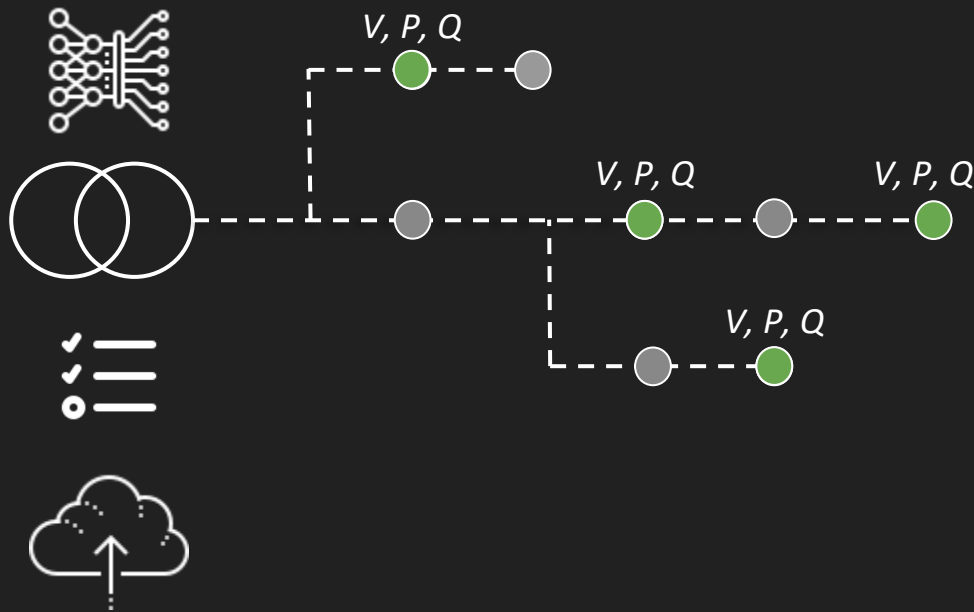
$$\begin{aligned} \frac{\partial \Delta(I_i^p)^p(\vec{x})}{\partial |V_i^p|} &= -(G_H^{pp} \cos \delta_i^p - B_H^{pp} \sin \delta_i^p) - \frac{(P_i^{pp})^p \cos \delta_i^p + (Q_i^{pp})^p \sin \delta_i^p}{|V_i^p|^2} \\ \frac{\partial \Delta(I_i^p)^p(\vec{x})}{\partial \delta_i^p} &= |V_i^p| (G_H^{pp} \sin \delta_i^p + B_H^{pp} \cos \delta_i^p) - \frac{(P_i^{pp})^p \sin \delta_i^p - (Q_i^{pp})^p \cos \delta_i^p}{|V_i^p|^2} \\ \frac{\partial \Delta(I_i^{pp})^p(\vec{x})}{\partial |V_i^p|} &= -(G_H^{pp} \sin \delta_i^p + B_H^{pp} \cos \delta_i^p) - \frac{(P_i^{pp})^p \sin \delta_i^p - (Q_i^{pp})^p \cos \delta_i^p}{|V_i^p|^2} \\ \frac{\partial \Delta(I_i^{pp})^p(\vec{x})}{\partial \delta_i^p} &= -|V_i^p| (G_H^{pp} \cos \delta_i^p - B_H^{pp} \sin \delta_i^p) + \frac{(P_i^{pp})^p \cos \delta_i^p + (Q_i^{pp})^p \sin \delta_i^p}{|V_i^p|^2} \end{aligned}$$

1. Network model (topology)
2. Impedance of all cables/conductors
3. Length of all line segments
4. Impedance of the transformer
5. The phase of each network connection
6. Load/generation for all connections
7. Setup time consuming non-linear power flow equations
8. Solve to estimate volts/current and determine network constraint excursions

Model Free

What is Model free?

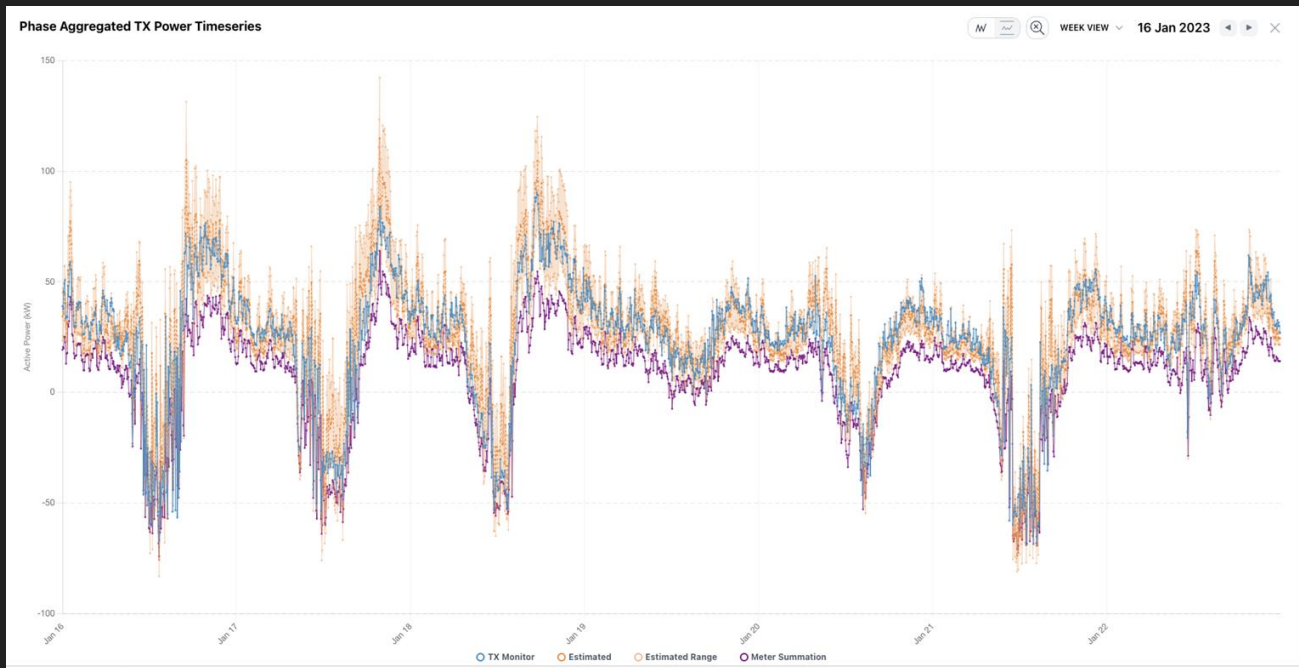
It's possible to use machine learning to capture the complex relationship between volts, active and reactive power



1. Utilise historical smart meter data
2. Train machine learning model to predict V given inputs P & Q
3. Test/validate model to confirm accuracy
4. Deploy model to estimate volts and determine network constraint excursions
5. Use cases
 - New DER connections
 - Network hosting capacity
 - Scenario planning
 - Dynamic operating envelopes

Model Free

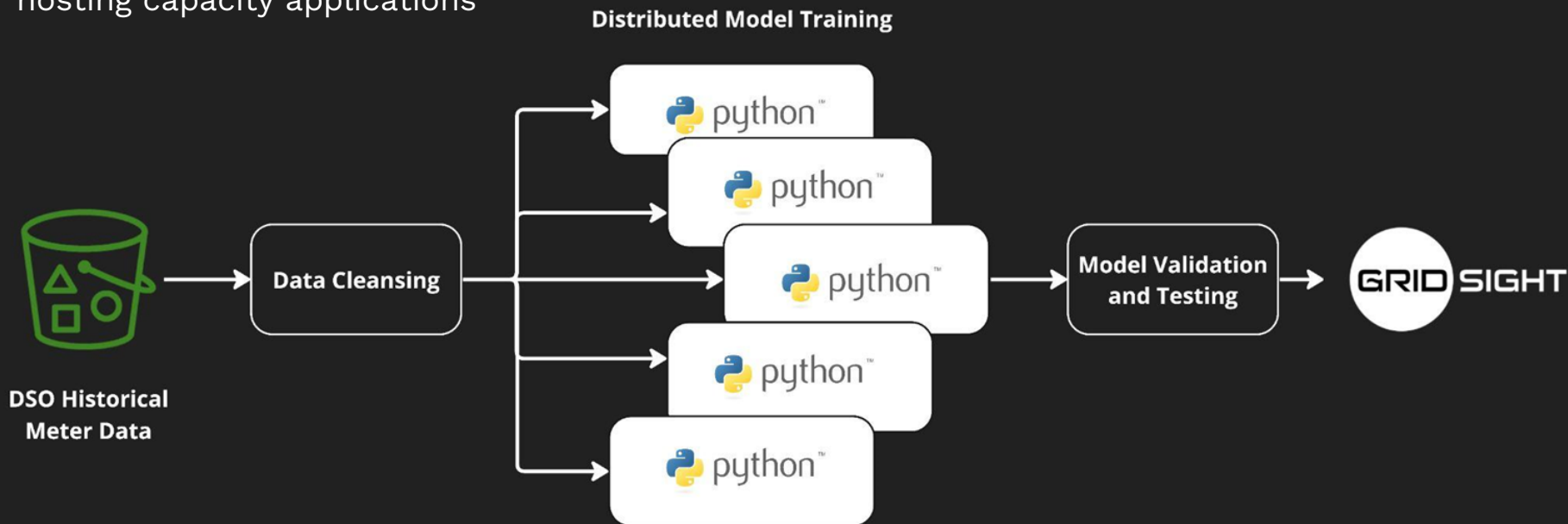
Combine validated topology, DER characterisation and meter data to create per timestamp load estimates



Model Free

Distributed Training at Scale

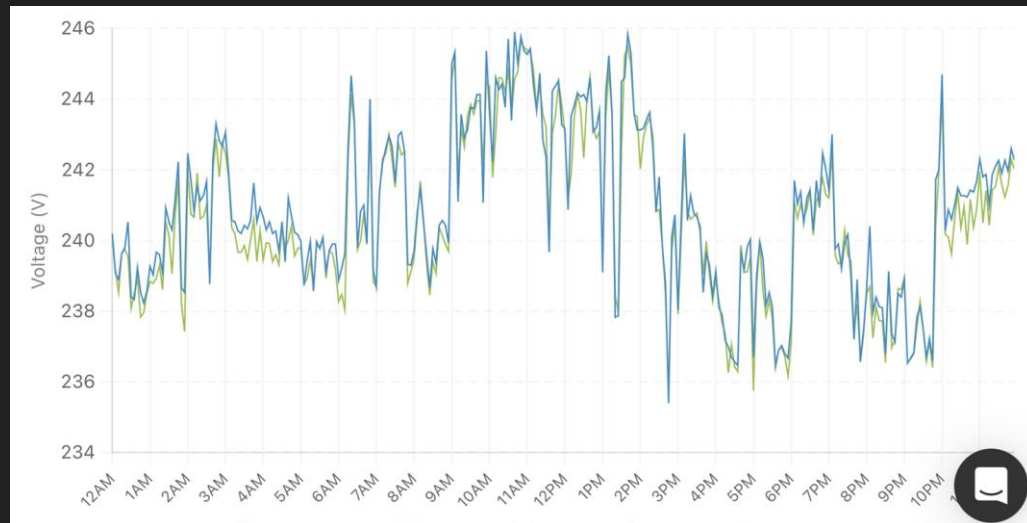
Gridsight have built a production pipeline to allow distributed training/testing of thousands of model free networks. These are then deployed within the Gridsight software platform for hosting capacity applications



DOE Simulations

Offline DOE Analytics

DSOs	2
Model free networks	339
Models trained	4516
Voltage prediction RMSE	1.01V
Max voltage error	6.24 V (avg)
Av. smart meter customers	~40%



Part of the Energy Queensland Group

— AMI Measurement
— Model Free Prediction

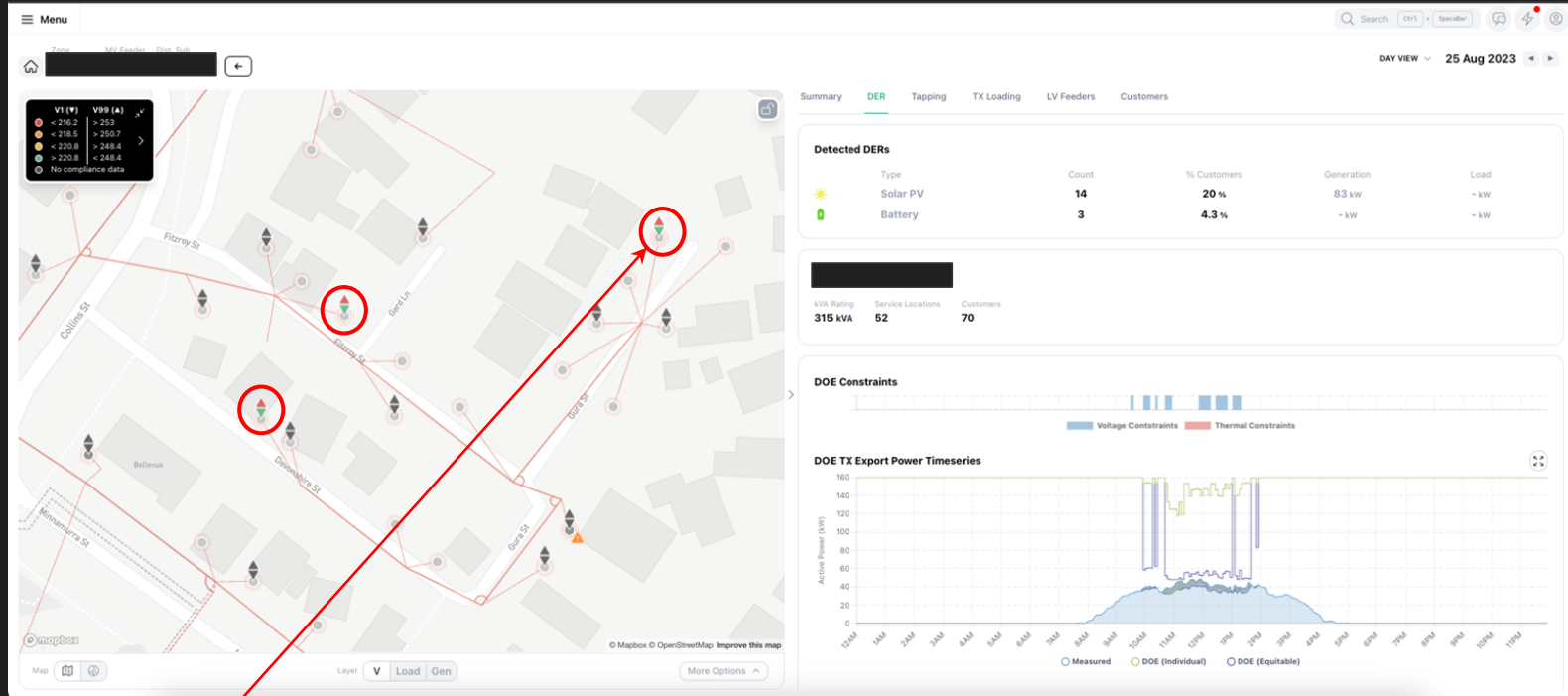
DOE Simulations

Algorithm Layer

Scale	~2800 solar sites	
Objective	Maximise exports	
Constraints	Voltage	$V_{\max} \leq 253$
	Thermal	$P_{\text{tot}} \text{ (kVA)} \leq \text{TX kVA rating}$
	Customer	Per-phase min DOE limit (3kW) Per-phase max DOE limit (10kW)
Allocation Method	Optimal	Individual DOE assigned to each customer
	Equitable	Each customer assigned same % limit based on upper DOE bound

DOE Simulations

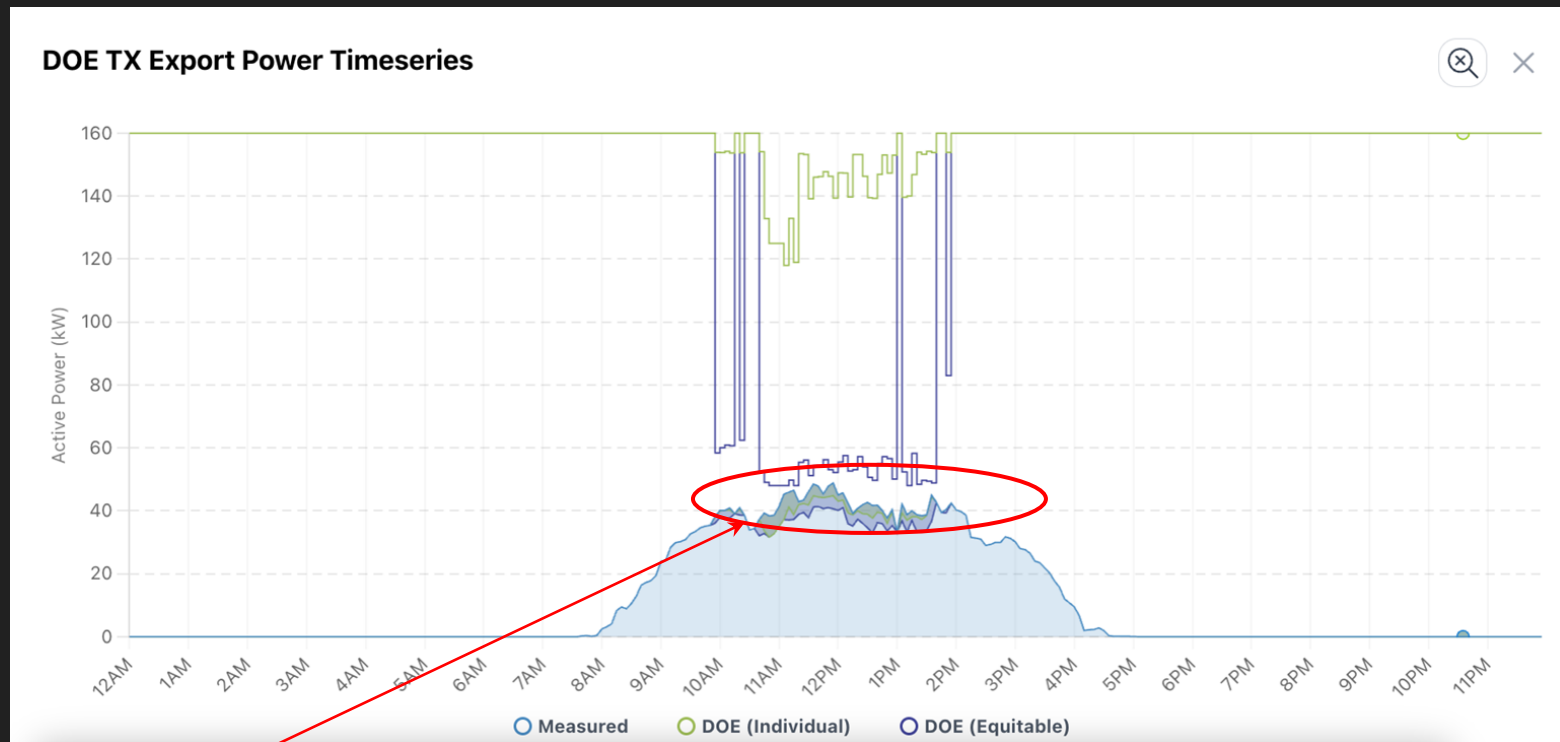
Data / Interface Layer - Identified Constraints



Voltage
constraints

DOE Simulations

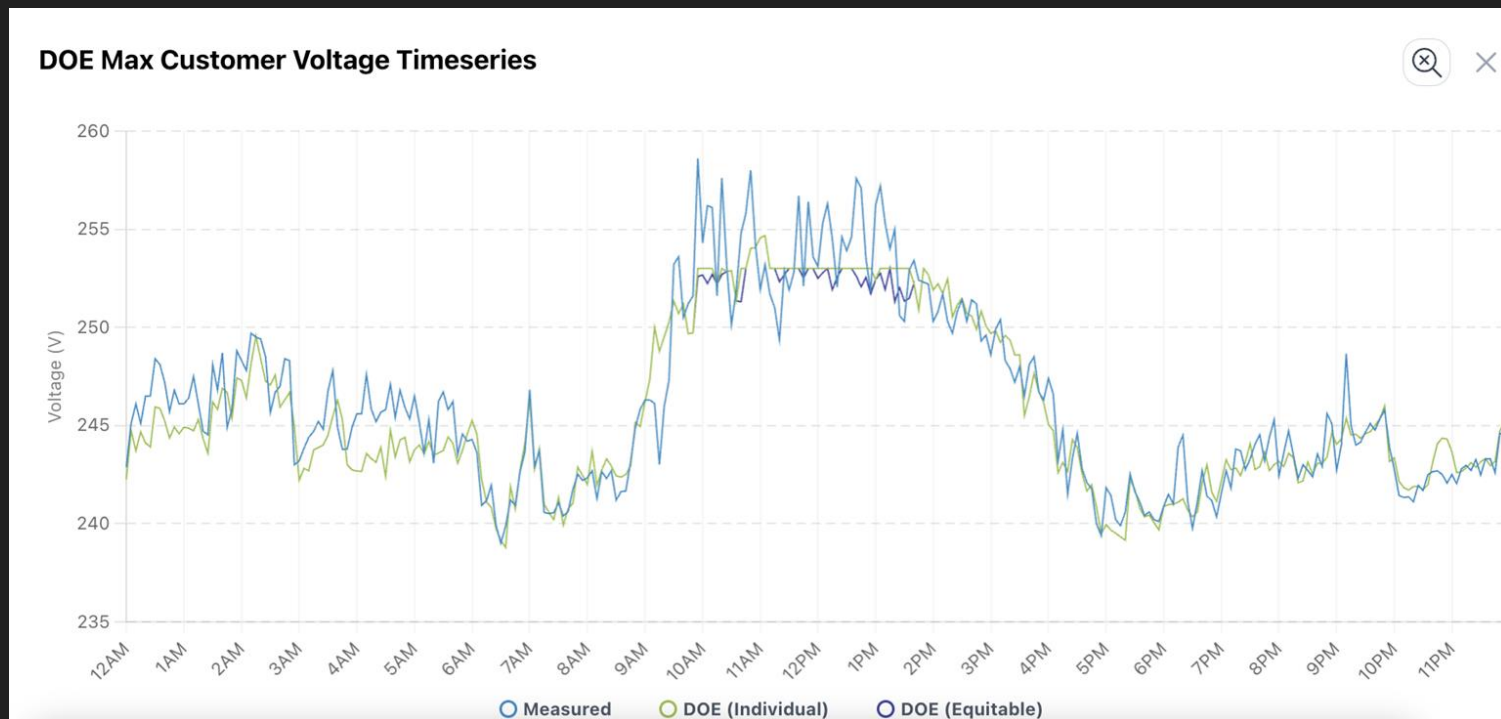
Data / Interface Layer - Simulated DOE Data



DOE
Curtailment

DOE Simulations

Data / Interface Layer - Simulated DOE Data



DOE Simulations

Data / Interface Layer - Easy to Interpret Analytics

🏠 > DOE Performance

Show All Time ☒ DAY VIEW 25 Aug 2023

Distribution Transformers

Customers

DOE Aggregations (All Time)

Aggregations of DOE Limits by distribution transformer. Click on column headings to sort by a different value.

DSTX [REDACTED] X 🔍 ⬇️

Filter (displaying 2 systems)

Allocation Method

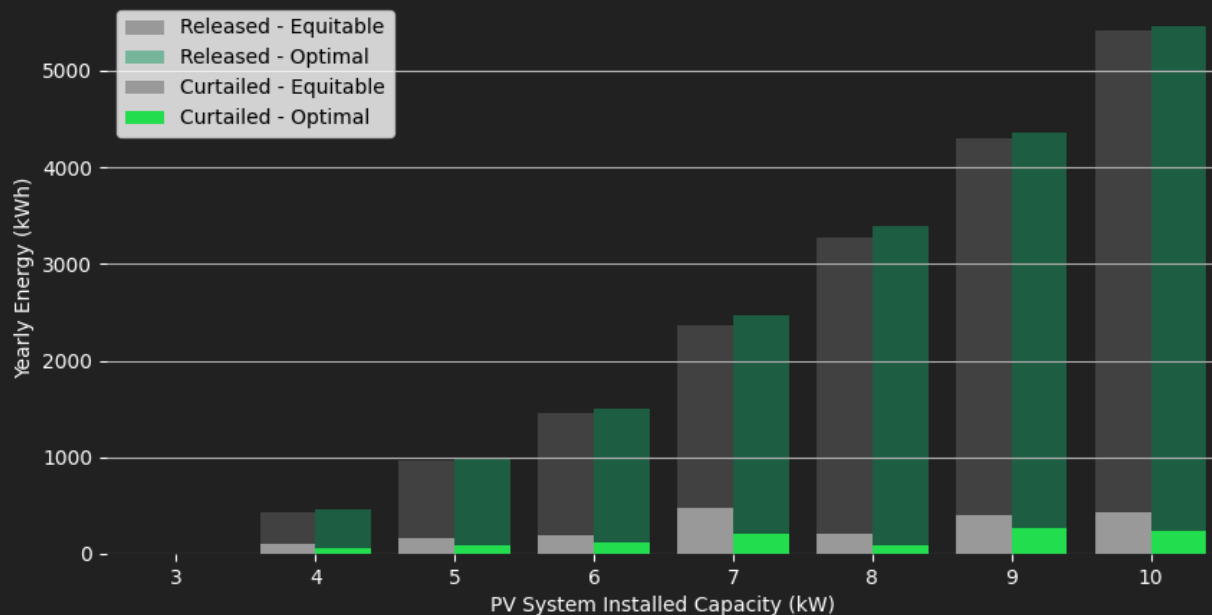
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DISTRIBUTION TRANSFORMER		PV INSTALLED CAPACITY	NET MINIMUM ALLOCATED DOE	NET MAXIMUM ALLOCATED DOE	PERCENTAGE TIME UPPER LIMIT UNAVAILABLE	TOTAL ENERGY CURTAILED	TOTAL ENERGY RELEASED
DSTX [REDACTED]	ALLOCATION METHOD	EQUITABLE 82.5 kW	0 kW/160 kW	160 kW/160 kW	11.5%	1539 kWh	896 kWh
DSTX [REDACTED]	ALLOCATION METHOD	INDIVIDUAL 82.5 kW	0 kW/160 kW	160 kW/160 kW	2.0%	498 kWh	1937 kWh

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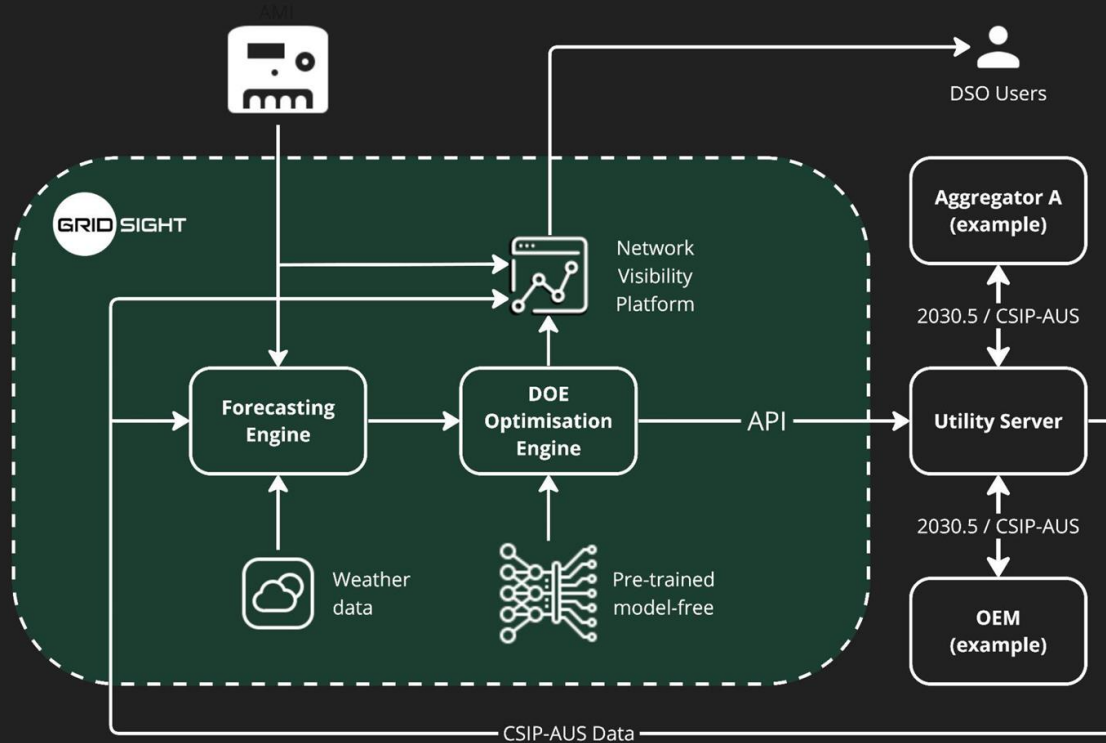
DOE Simulations

Data / Interface Layer - Allocation Comparison



Real-Time Calculations

Current Architectures



Future Work

- Focus on import limits
 - Residential/commercial EV charging DOE
- Scaling near real-time optimisation in Aus
 - Most new solar customers will be DOE enabled
- Exploration of dynamic hosting capacity opportunities in the US, including MV thermal constraint considerations, and peak load shifting
- Inclusion of minimum demand constraints



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