EDGE Project

Operating Envelopes: Update

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Network Advisory Group Meeting
22nd July, 2021

Outline

1. Recap
   - Definitions, Data, General Operating Envelope Architecture

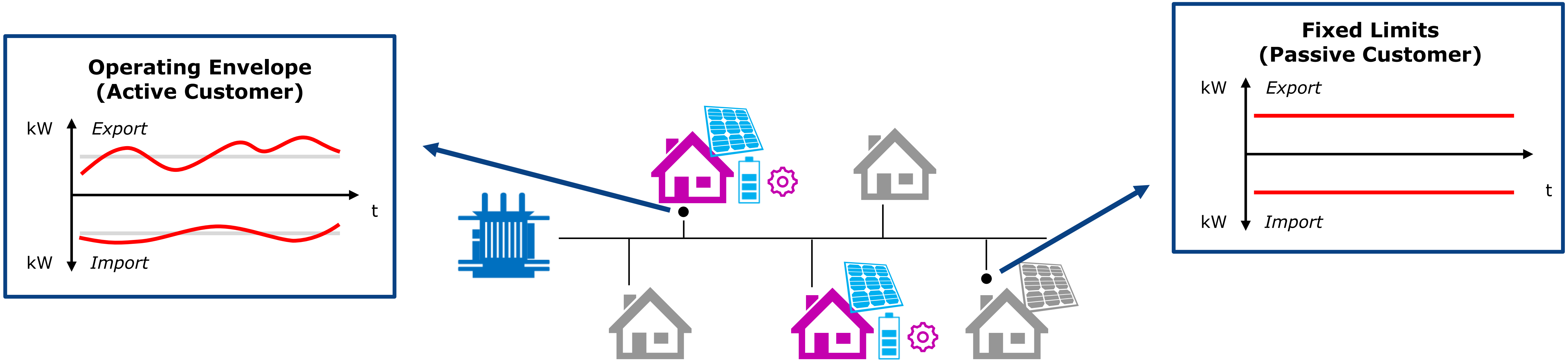
2. Overview of Objective Functions (aka Allocation Principles)
   - Equal Opportunity and Maximise Services

3. Update on Network Modelling and Lessons Learnt

1. Recap

Recap: Definitions

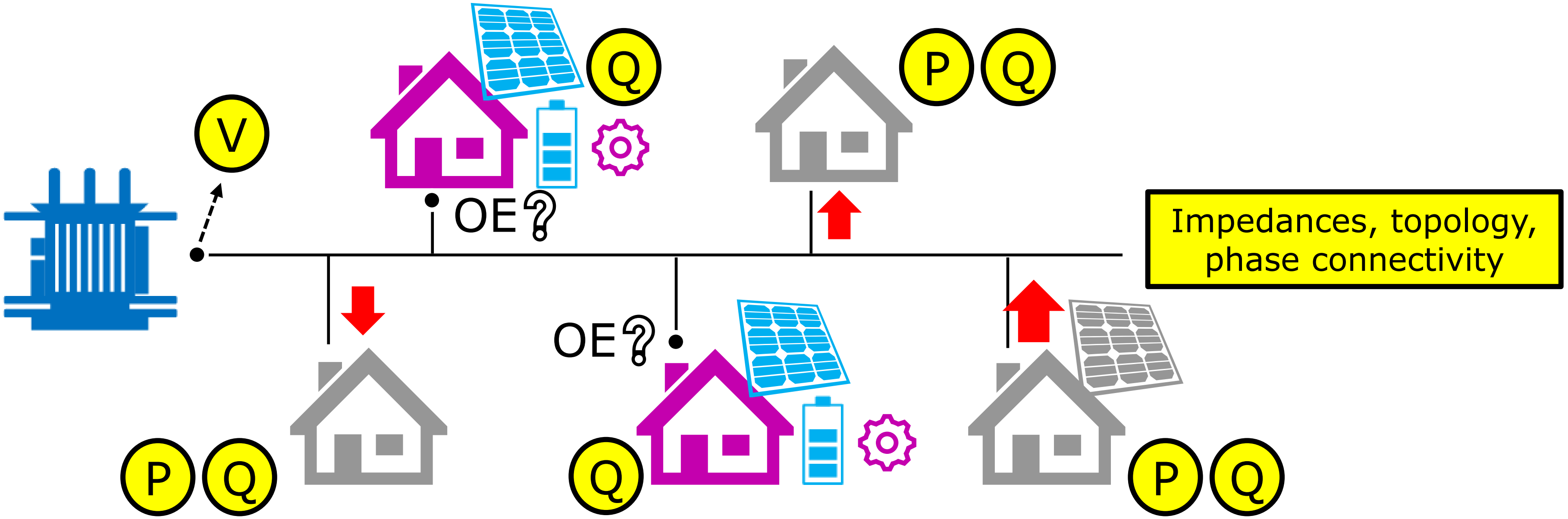
- **Active Customer**: Customer engaged with an aggregator
- **Passive Customer**: 'Normal' customer with or without DER
- **Operating Envelopes (OEs)**: Time-varying export/import limits* at the network connection point of active customers



* First year of EDGE, **OE focus is on active power**. No reactive power services.

Recap: Key Input Data to Calculate OEs 1/2

- To calculate the OEs we need to know the state of the rest of the network
  - ✓ Full three-phase **LV network** model or full **SWER*** **network** model (from the iso trafo)
  - ✓ Net demand (P, Q) of passive customers** and Q of active customers**
  - ✓ Voltage magnitudes (V) at head of feeder**



Impedances, topology, phase connectivity

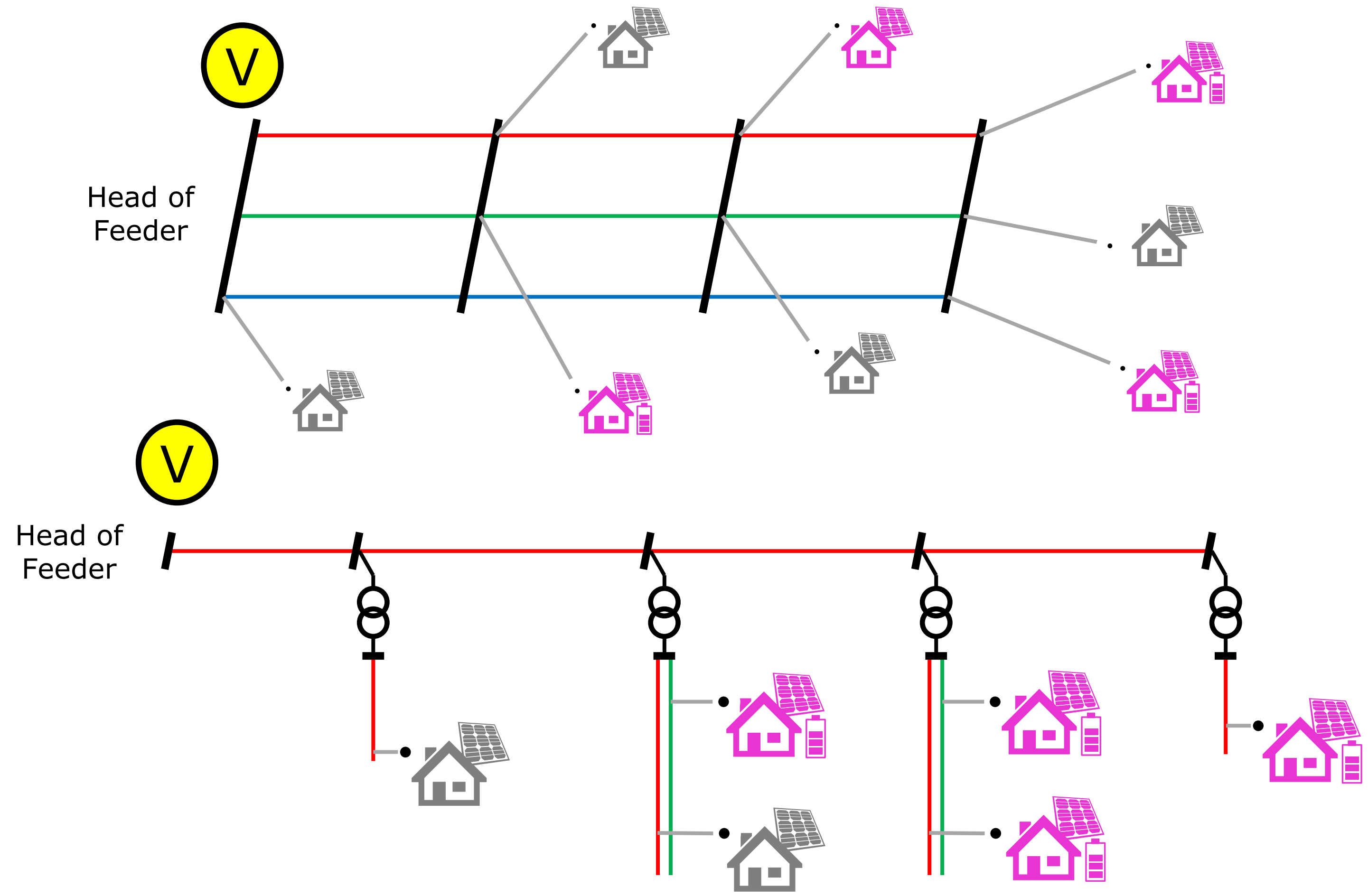
* SWER: Single Wire Earth Return
** **All forecast values** (e.g., every 15 min for the next 6 hours)

Recap: Key Input Data to Calculate OEs 2/2

- Each type of network needs to be treated slightly different.

LV Network

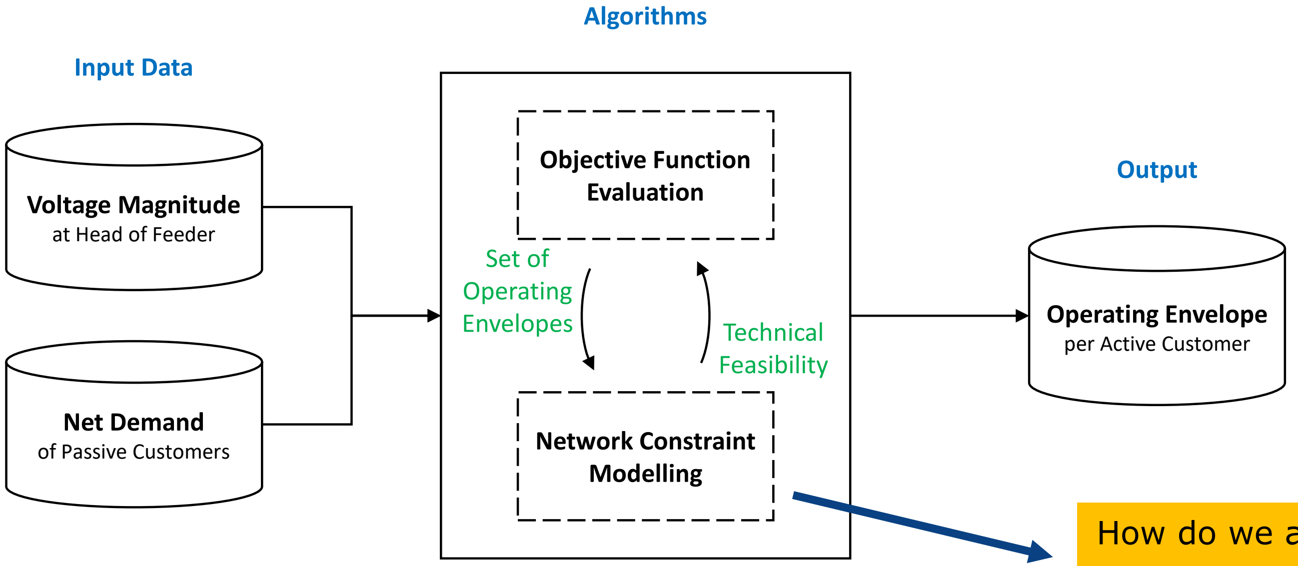
SWER Network



OE calculations also need to be slightly different.

Recap: General OE Architecture 1/2

- **Iterative approach** to determine the ‘best’ set of OEs for active customers
  - ✓ Done for each interval in the forecast (e.g., every 15 min)
  - ✓ Done for export and imports separately
  - ✓ Fully utilises the available voltage headroom/legroom and thermal capacity
  - ✓ Heuristic approach → Set of rules aligned with the objective function



Input Data

Voltage Magnitude at Head of Feeder

Net Demand of Passive Customers

Algorithms

Objective Function Evaluation

Set of Operating Envelopes

Technical Feasibility

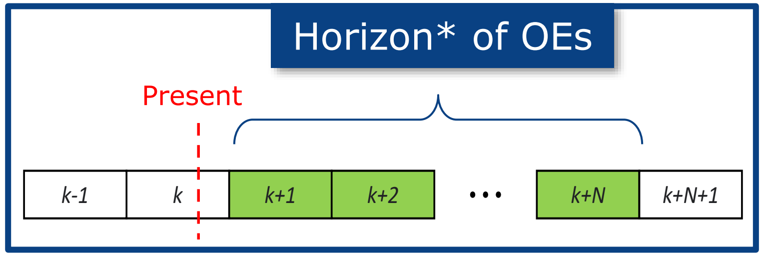
Network Constraint Modelling

Output

Operating Envelope per Active Customer

How do we assess if a given set of OEs works?
→ We run multiple simplified 3ϕ power flows

Recap: General OE Architecture 2/2



Horizon* of OEs

Input Data (k, …, k+N)

Forecast
Voltage Magnitudes
at Head of Feeder

Forecast
Net Demand
of Passive Customers and
Q of Active Customers

Exports

Objective Function Evaluation

Set of Operating Envelopes

Technical Feasibility

Network Constraint Modelling

Output (k+N)

Operating Envelope
per Active Customer

Interval k+N

Interval k+2

Interval k+1

Imports

Objective Function Evaluation

Set of Operating Envelopes

Technical Feasibility

Network Constraint Modelling

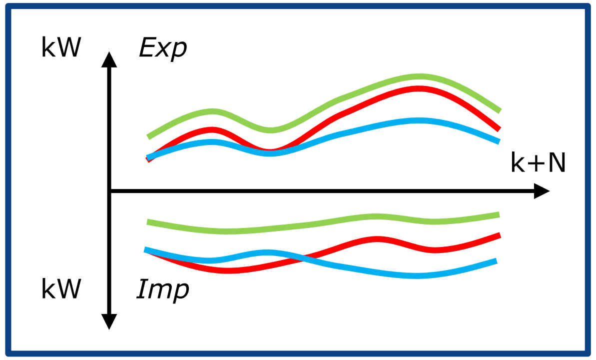
Output (k+N)

Operating Envelope
per Active Customer

Interval k+N

Interval k+2

Interval k+1



* E.g., Next 6 hours with 15 min intervals

2. Overview of Objective Functions

(aka Allocation Principles)

Objective Function: Equal Opportunity

Philosophy and Considerations

- Every active customer receives the *same/proportional* OE
  - Same: Exact same kW regardless the size of DER
  - Proportional: Pro-rata based on DER size

- General Process
  a) Apply same/proportional OEs to all active customers and check constraint violations
  b) Explore other OE values until the largest one (w/o constraint violations) has been found

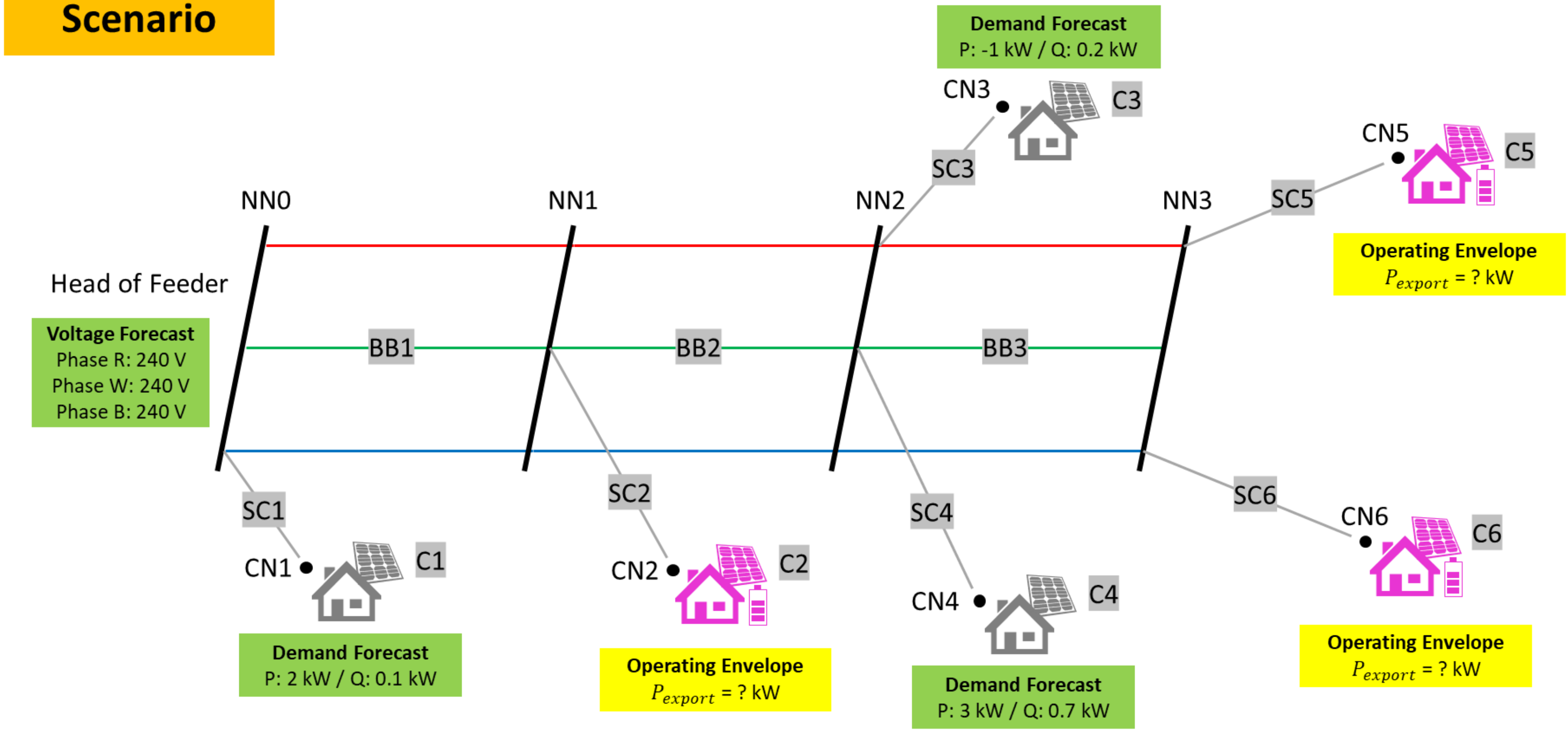
- Implemented Process
  a) Start at 100% OE (relative to the total kW/kVA of inverters)
  b) Decrease by 1% until no constraint violations

Faster, if OE is expected to >50% most of the time

Objective Function: Equal Opportunity

Numerical Example

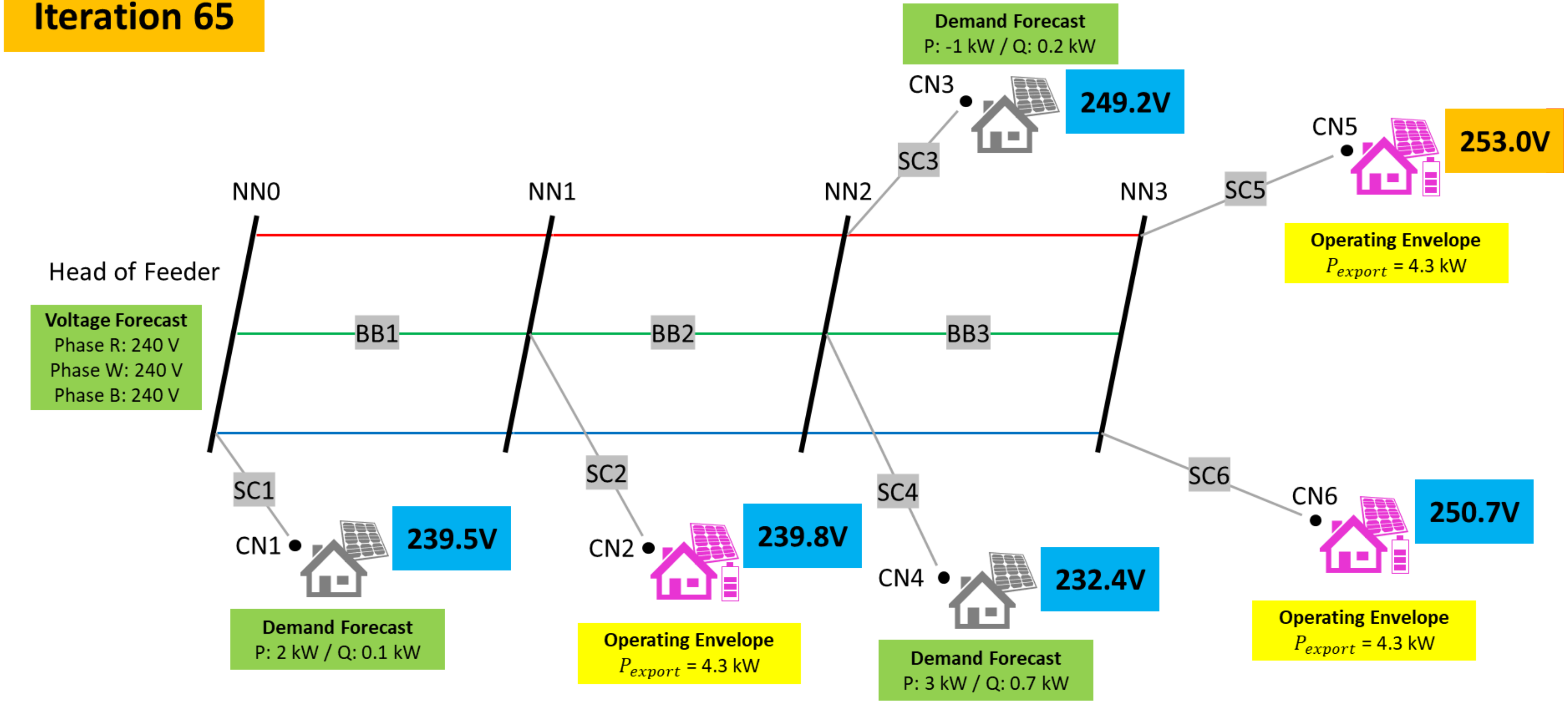
Scenario



Objective Function: <u>Equal Opportunity</u>

Numerical Example

Iteration 65



Demand Forecast
P: -1 kW / Q: 0.2 kW

Voltage Forecast
Phase R: 240 V
Phase W: 240 V
Phase B: 240 V

Operating Envelope (CN5)
P_{export} = 4.3 kW

Demand Forecast
P: 2 kW / Q: 0.1 kW

Operating Envelope
P_{export} = 4.3 kW

Demand Forecast
P: 3 kW / Q: 0.7 kW

Operating Envelope
P_{export} = 4.3 kW

<u>Final</u> OEs (Export Limits): 4.3 kW for C2, C5 and C6. Total of 12.9 kW.

Objective Function: Maximise Services

Philosophy and Considerations

- Maximise the aggregated operating envelopes (potential volume of services)

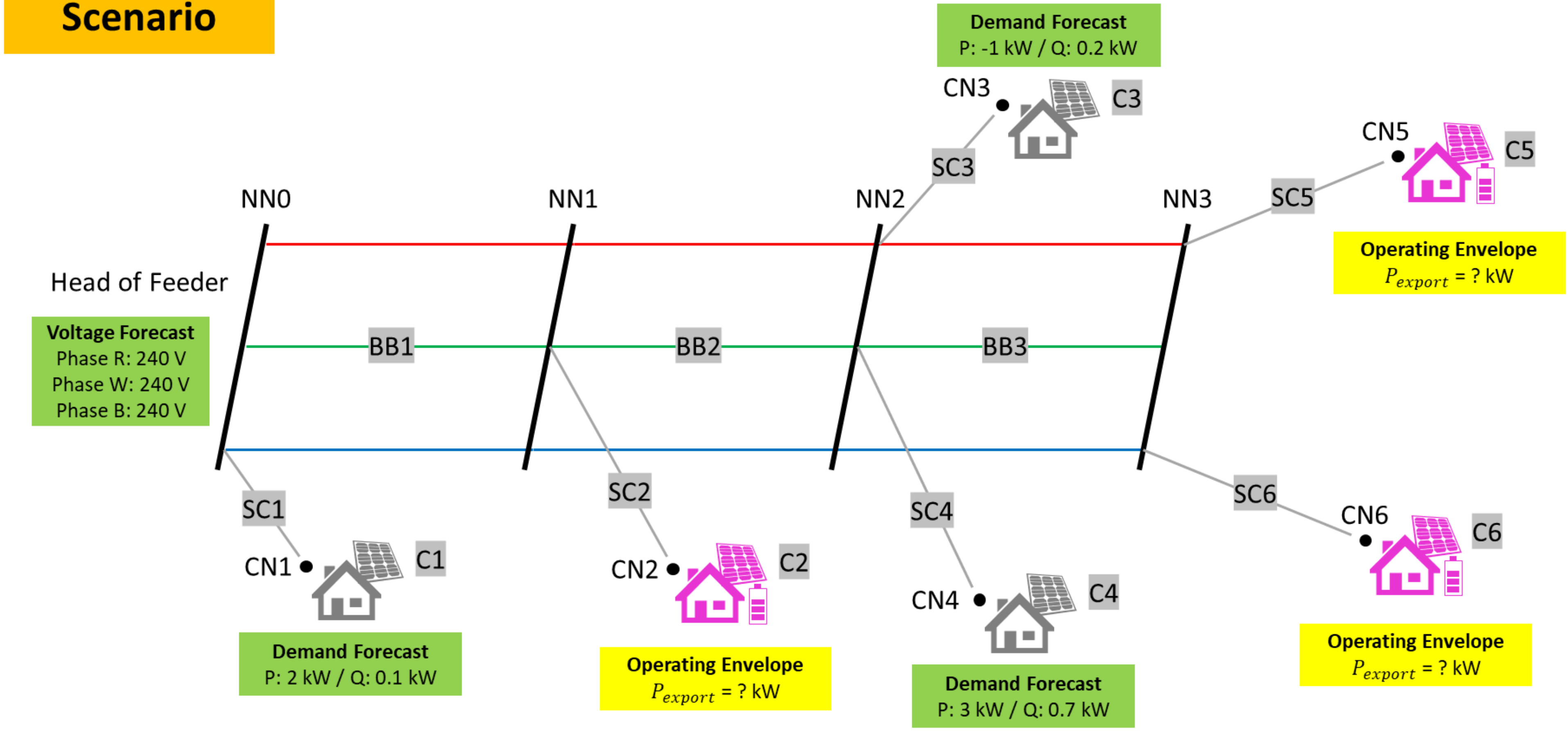
- General Process
  - a) Pick customers more sensitive to voltage issues
  - b) Apply OEs to all active customers and check constraint violations
  - c) Reduce the OEs of the sensitive customers

- Sensitive customers are different for each type of feeder
  - Three-Phase feeders: Active customer with the highest voltage (per phase)
  - SWER feeder: Active customer with the highest voltage

Objective Function: Maximise Services

Numerical Example

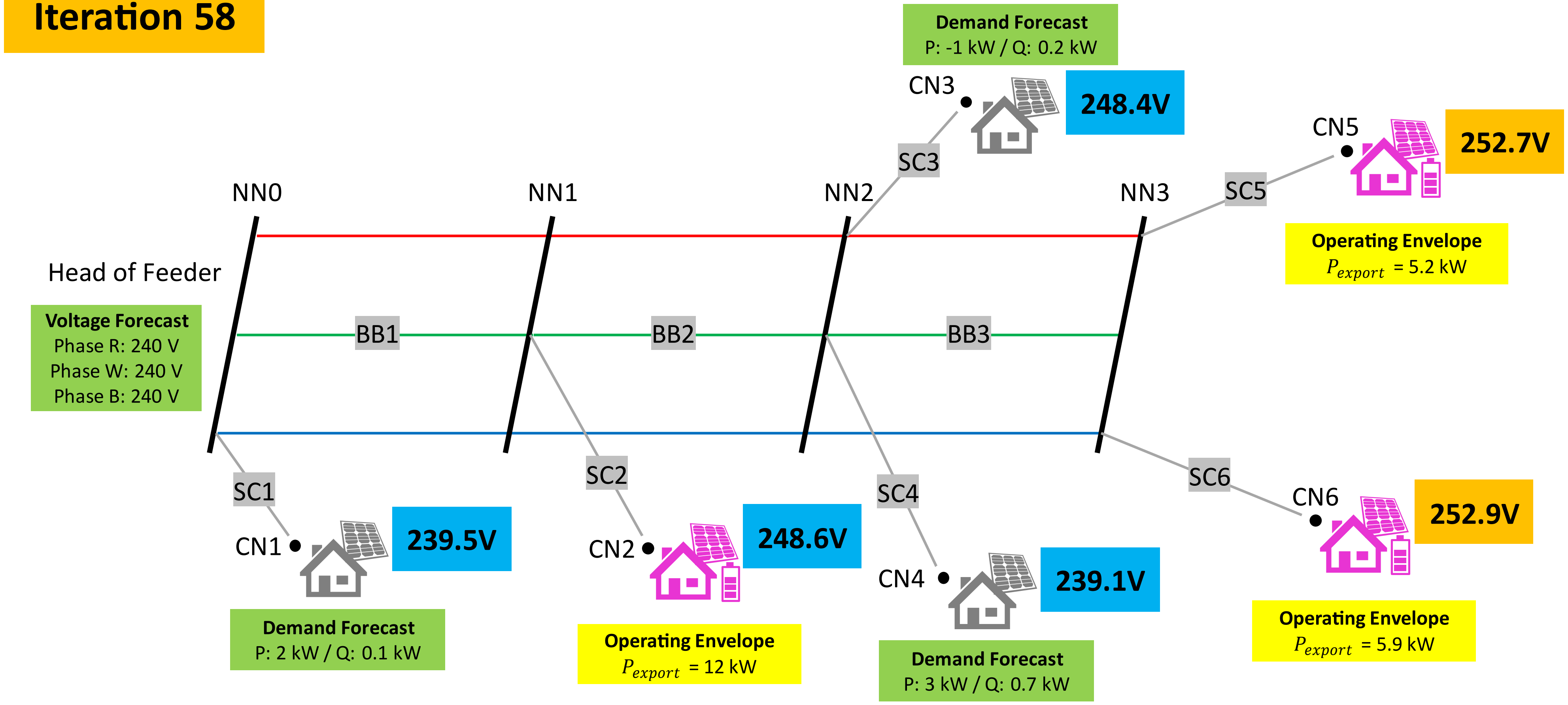
Scenario



Objective Function: Maximise Services

Numerical Example

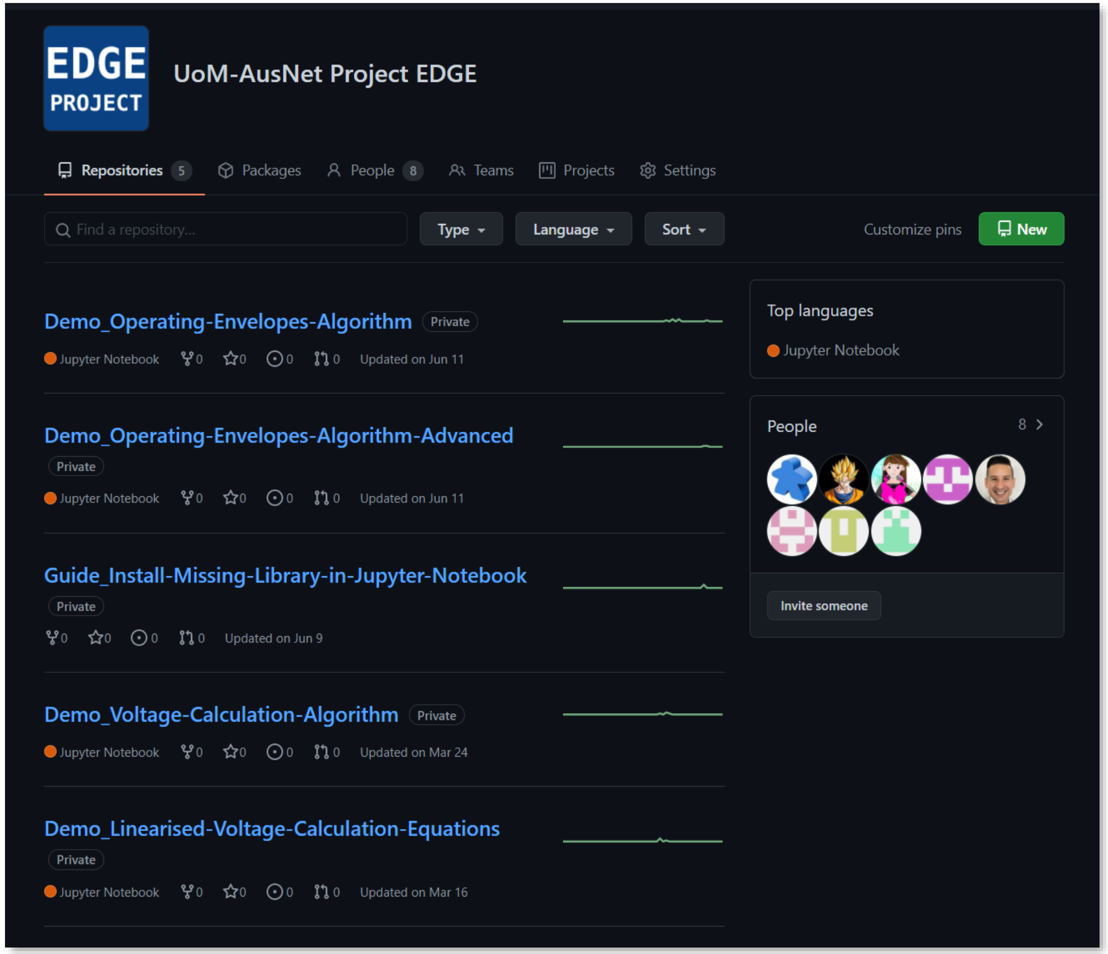
Iteration 58



<u>Final</u> OEs (Export): 12/5.2/5.9 kW for C2/C5/C6. Total of 23.1 kW.

How are we transferring all these algorithms?

GitHub and Jupyter Notebook



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Demo_Operating-Envelopes-Algorithm Private
Jupyter Notebook 0 0 0 0 Updated on Jun 11

Demo_Operating-Envelopes-Algorithm-Advanced Private
Jupyter Notebook 0 0 0 0 Updated on Jun 11

Guide_Install-Missing-Library-in-Jupyter-Notebook Private
0 0 0 0 Updated on Jun 9

Demo_Voltage-Calculation-Algorithm Private
Jupyter Notebook 0 0 0 0 Updated on Mar 24

Demo_Linearised-Voltage-Calculation-Equations Private
Jupyter Notebook 0 0 0 0 Updated on Mar 16

Top languages
Jupyter Notebook

People 8

Invite someone

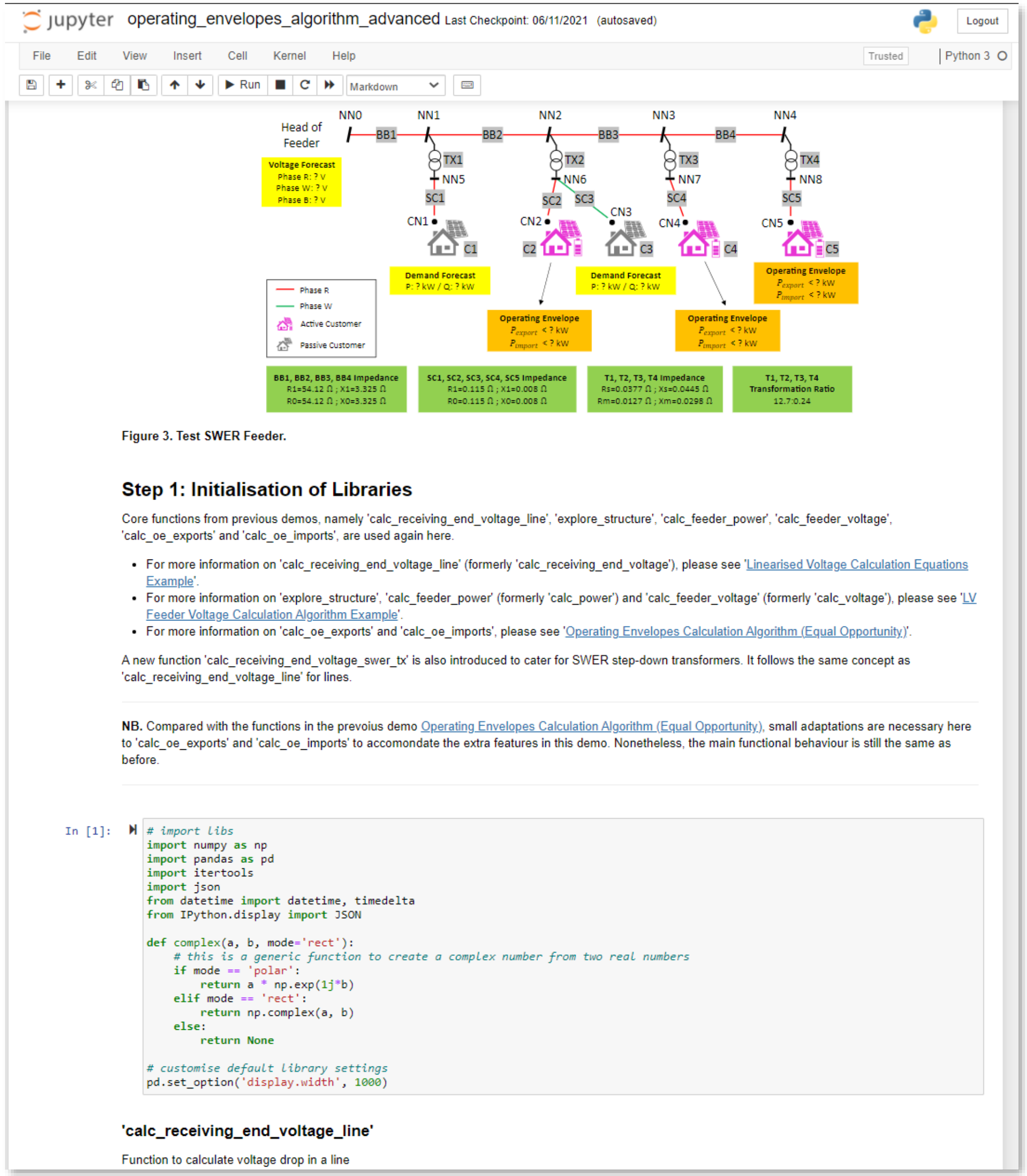


Figure 3. Test SWER Feeder.

Step 1: Initialisation of Libraries

Core functions from previous demos, namely 'calc_receiving_end_voltage_line', 'explore_structure', 'calc_feeder_power', 'calc_feeder_voltage', 'calc_oe_exports' and 'calc_oe_imports', are used again here.

- For more information on 'calc_receiving_end_voltage_line' (formerly 'calc_receiving_end_voltage'), please see 'Linearised Voltage Calculation Equations Example'.
- For more information on 'explore_structure', 'calc_feeder_power' (formerly 'calc_power') and 'calc_feeder_voltage' (formerly 'calc_voltage'), please see 'LV Feeder Voltage Calculation Algorithm Example'.
- For more information on 'calc_oe_exports' and 'calc_oe_imports', please see 'Operating Envelopes Calculation Algorithm (Equal Opportunity)'.

A new function 'calc_receiving_end_voltage_swer_tx' is also introduced to cater for SWER step-down transformers. It follows the same concept as 'calc_receiving_end_voltage_line' for lines.

NB. Compared with the functions in the prevoius demo Operating Envelopes Calculation Algorithm (Equal Opportunity), small adaptations are necessary here to 'calc_oe_exports' and 'calc_oe_imports' to accomondate the extra features in this demo. Nonetheless, the main functional behaviour is still the same as before.

In [1]:

```
# import libs
import numpy as np
import pandas as pd
import itertools
import json
from datetime import datetime, timedelta
from IPython.display import JSON

def complex(a, b, mode='rect'):
    # this is a generic function to create a complex number from two real numbers
    if mode == 'polar':
        return a * np.exp(1j*b)
    elif mode == 'rect':
        return np.complex(a, b)
    else:
        return None

# customise default library settings
pd.set_option('display.width', 1000)
```

'calc_receiving_end_voltage_line'

Function to calculate voltage drop in a line

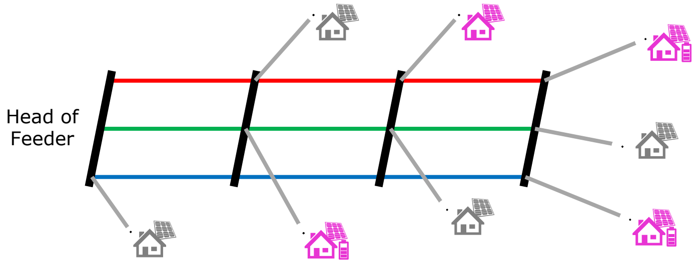
OE algorithms are generic (network-agnostic)

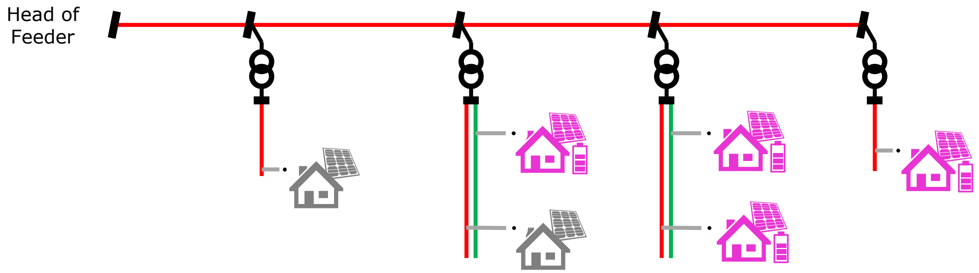
3. Update on Network Modelling and Lessons Learnt

Current Progress on Network Models

- Network models need to be valid (adequate) for accurate calculations

Trial Sites		Topology	Phase Groups	Impedance
Three-Phase LV Feeder	Hume 1 Site A	☑ ▨ ▨	☑	▨ ▨ ▨
	Hume 1 Site B	☑ ☑ ▨	☑	▨ ▨ ▨
SWER Feeder (MV+LV)	Hume 1 Site C	☑ ☑ ▨	☑	▨ ▨ ▨
	Hume 1 Site D	☑ ☑ ▨	☑	▨ ▨ ▨

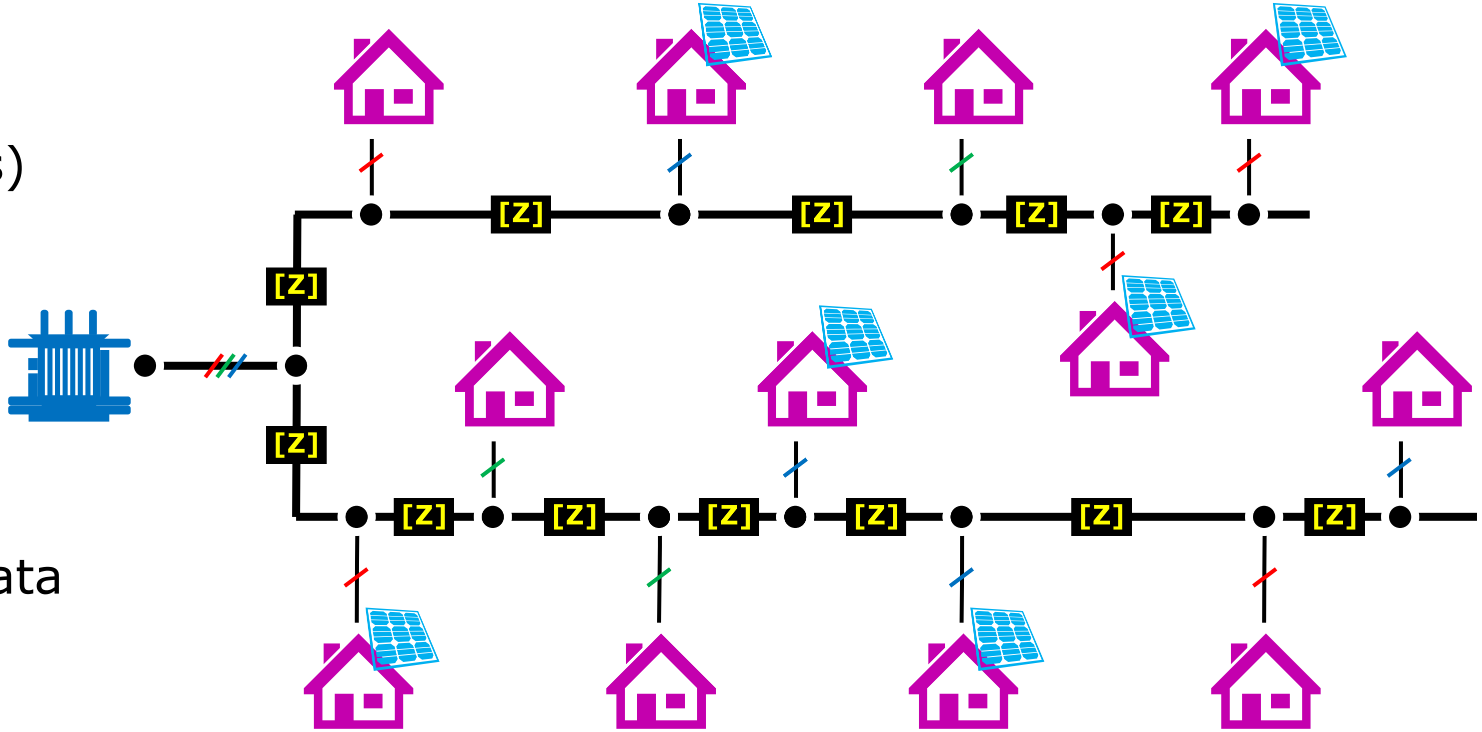




Overview of Network Models

- They are **<u>the foundation</u>** of model-based algorithms

- **<u>Key information</u>** required
  - **Topology** (i.e., interconnections)
  - **Phase groupings**
  - **Impedances**



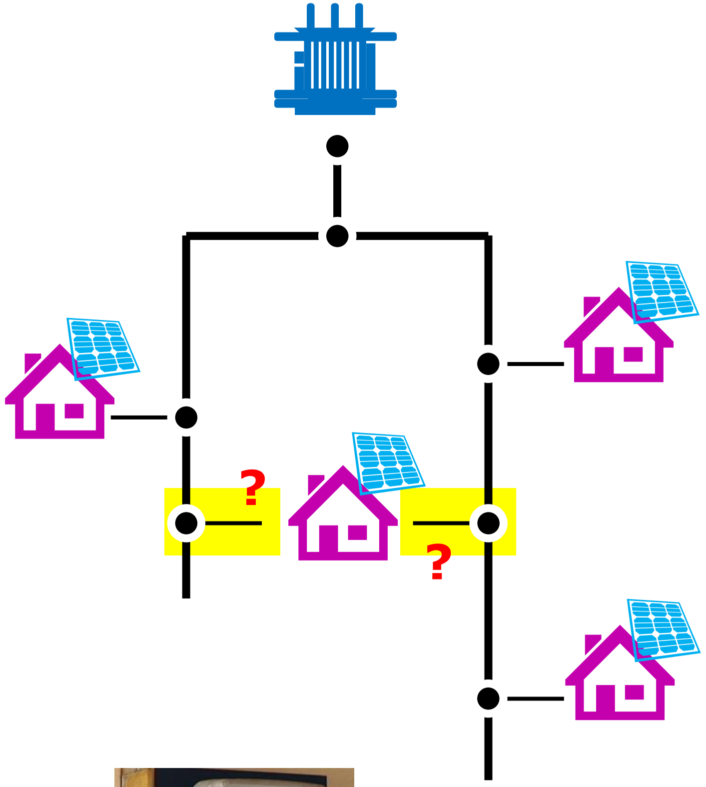
- Main challenges
  - Incorrect/incomplete topology data
  - Unrecorded phase groupings
  - Inaccurate impedances

More details on the *<u>challenges</u>* and *<u>lessons learnt</u>* next.

Challenges & Lessons Learnt

Topology

- Existing database may contain **incorrect information**
  - More prominent in three-phase feeders (urban)
  - SWER feeders (rural) are less error-prone
- **Desktop-based analysis can help** to identify mistakes
  - Smart meter data is a key enabler
  - Head of feeder monitoring data is important
  - Tedious and time consuming
- **Site audits are required** in some cases to validate the actual topology



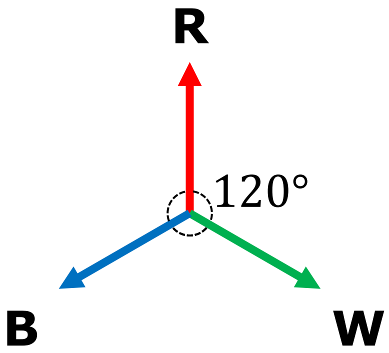
Challenges & Lessons Learnt

Phase Groupings

- Customers' phase groupings are **<u>typically not recorded</u>**

- **<u>Data-driven techniques are exploited</u>** to identify phase groupings
  - Smart meter data is a key enabler

- Phase grouping ≠ true phase
  - Phase grouping: 1, 2 and 3
  - True phase: R, W and B
  - Identification of true phases requires a site audit and specialised devices (PMUs)



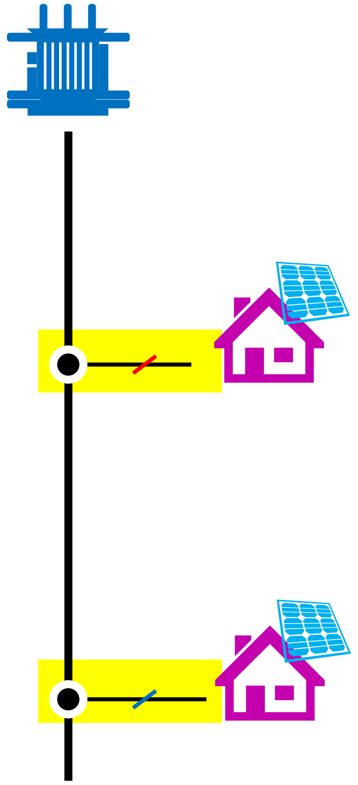
- **<u>The least difficult issue</u>** to address

Challenges & Lessons Learnt

Impedances

- Typically estimated using **conductor type + estimated length**
  - Can be very **inaccurate**
  - **Particularly for service cables**

- <u>**Data-driven techniques are exploited**</u> to validate impedances
  - Smart meter data is a key enabler
  - Head of feeder monitoring data is crucial
  - Correct topology data is a pre-requisite



Further Reading 1/2

Grid and Market Services From the Edge

Using Operating Envelopes to Unlock Network-Aware Bottom-Up Flexibility

By Michael Z. Liu, Luis (Nando) Ochoa, Shariq Riaz, Pierluigi Mancarella, Tian Ting, Jack San, and John Theunissen

THE PROLIFERATION OF DISTRIBUTED ENERGY resources (DERs) at the edge of the grid, such as residential solar photovoltaics and batteries, has created the opportunity for aggregators to manage multiple customers (hereafter referred to as *active* customers) and their DERs to participate in energy and ancillary service markets and provide various local and system-level grid services. These aggregators strive to create a large portfolio involving thousands of active customers and thus achieve the flexibility to create a substantial aggregated response at the system level.

At the same time, if this aggregated response is not adequately managed, the simultaneous power exports (or imports) can result in voltages and currents well beyond the limits of the distribution network. As the volume of DERs participating in system and market operation increases, the more necessary it is to ensure network integrity. But the big barrier for most distribution companies is that they cannot directly control DERs or aggregators because of the unbundling rules of deregulated electricity markets.

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> Setting the length of the intervals, the length of the horizon, and how often operating envelopes are calculated have associated tradeoffs between accuracy and complexity.

Currently, a common solution to mitigate excessive power flows is a region-wide, fixed export limit at customer connection points (e.g., the 5-kW limit for single-phase connections in Australia). However, such a fixed limit can be overly prohibitive (as it is determined based on worst-case scenarios) and/or inadequate (as it can become outdated when DER penetration grows). To this end, an alternative approach called *operating envelopes* can become a more effective and efficient way to facilitate bottom-up system-level market participation and provision of grid services from the edge of the grid.

In this concept, distribution companies first calculate, in real time or day ahead, operating envelopes (time-varying export or import limits) at the connection point of the customers' premises (where the meter is located). This information is then given to aggregators to consider as a constraint when deciding how to manage their DER portfolio for energy and ancillary services participation. Furthermore, local market and pricing mechanisms are envisioned to be managed by the distribution company, which could price network-related constraints and services in an integrated manner with wholesale energy and ancillary services.

A key advantage of the operating envelope approach is that it allows the distribution companies to ensure network integrity without having direct control of the DERs or the aggregator. This also enables maximization of the capacity that can be allocated in near real time to different DERs, thus maximizing the volume of flexibility that can be provided upstream. Moreover, the development of network-aware local services that ar
can increase the ove
ent "products" and th
aggregators to impro
their bids across mul
their customers.

This article provides foundational insights on what operating envelopes are and how they can facilitate the provision of flexibility and grid services and relevant market participation for DER aggregations. We discuss how operating envelopes could be practically implemented by industry, including an overall architecture and an example methodology for determining operating envelopes. We also look at the role of reactive power to access network capacity for provision of flexibility, the impact of flexibility temporal aspects on market interaction, and the potential challenges that need to be overcome to make operating envelopes a reality.

Integrating Local and System-Level Network and Market Services

Traditionally, energy and ancillary services are acquired from resources within the transmission network, and the interactions between the transmission and distribution networks have been straightforward. Local network support in the distribution network is typically provided through the network assets owned by the distribution companies. Consequently, as the opportunity for residential DERs to provide both system-level services and local network support emerges, a new architecture is also necessary to enable these interactions across the entire power system. Under this new paradigm, three key roles are envisaged to enable and facilitate the emerging activities from the edge of the grid (e.g., aggregation of residential DERs):

- ✓ the distribution system operator (DSO)
- ✓ the distribution market operator (DMO, which in some jurisdictions might be associated with the DSO in different ways)
- ✓ the aggregator.

The DSO is the evolutionary form of a distribution company, an entity now also responsible for actively managing network access limits of active customers by calculating and issuing operating envelopes. The aggregator is responsible for managing the DERs of active customers to participate in wholesale markets, including ensuring their availability when services are needed, making bids in the relevant mar-

interacting with the bulk energy system and markets.

In addition to the three key roles, a distribution market platform is also required as a central transaction hub to facilitate the interactions among all participants in the day-to-day operations. This central hub enables a more transparent approach for the parties involved, which can be particularly important when there are multiple aggregators. An infographic summarizing the interactions among participants in the distribution market platform and the key activities under the proposed architecture is shown in Figure 1.

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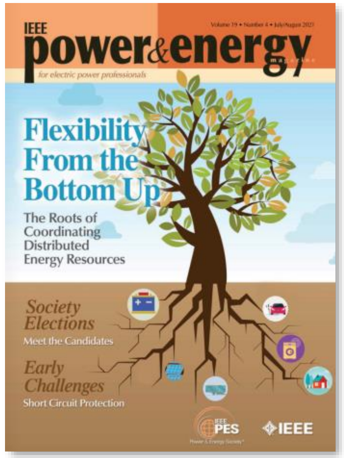

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Further Reading 2/2

- OEs and General Algorithms/Architectures
  - “Ensuring distribution network integrity using dynamic operating limits for prosumers”, IEEE Transactions on Smart Grid, Apr 2021 (PDF)
  - “DER and Network Integrity: Meter-Level Operating Envelopes”, IEEE Smart Grid Webinar, Dec 2020 (Link)
  - “Impacts of price-led operation of residential storage on distribution networks: An Australian case study”, IEEE PES PowerTech 2019, Jun 2019 (PDF)
  - “Managing residential prosumers using operating envelopes: An Australian case study”, CIRED Workshop 2020, Sep 2020 (PDF)
  - “Assessing the effects of DER on voltages using a smart meter-driven three-phase LV feeder model”, Electric Power Systems Research, Dec 2020 (PDF)

- Objective Function (aka Allocation Principles)
  - “On the fairness of PV curtailment schemes in residential distribution networks”, IEEE Transactions on Smart Grid, Sep 2020 (PDF)
  - “Operating envelopes for prosumers in LV networks: A weighted proportional fairness approach”, IEEE/PES Innovative Smart Grid Technologies ISGT Europe 2020, Oct 2020 (PDF)

Thanks!

Questions?

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