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Active network management in LV networks: a case study in the UK

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Outline

1. Main challenges facing distribution networks
2. Active Network Management
3. OpenLV project
4. Optimal Power Flow
5. Case study
6. Conclusions

1. Main challenges facing distribution networks

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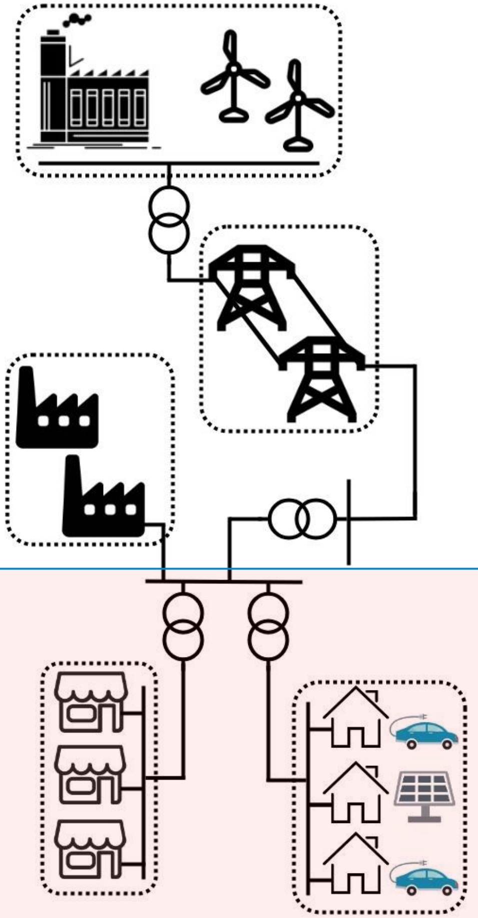
Power system structure



- Bulk power generation
- Transmission network
- Distribution network
- **Low-voltage network**

Large industrial customers

Commercial customers

Domestic customers

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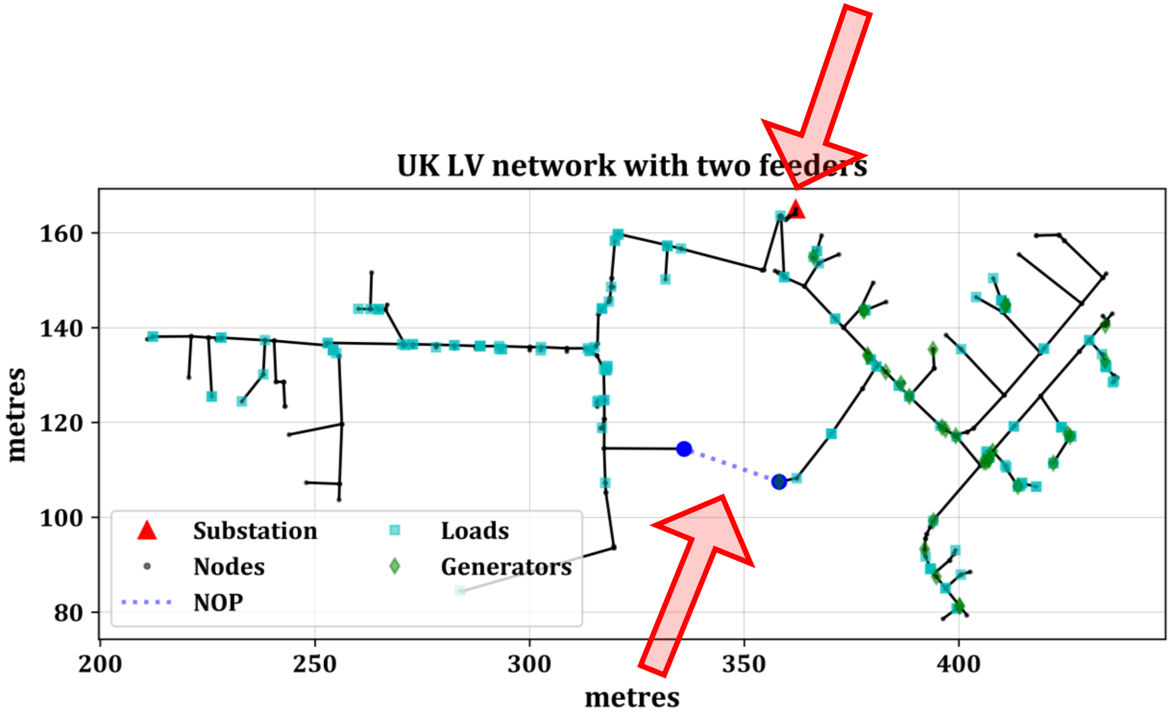
Characteristics of LV networks:

- Radial operation with **no active management** of the power flows
- Network **reconfiguration only in case of faults**
- **Uneven distribution of the load/generation** between phases
- Majority of **loads are connected to a single phase**
- Line currents and voltages are **unbalanced**



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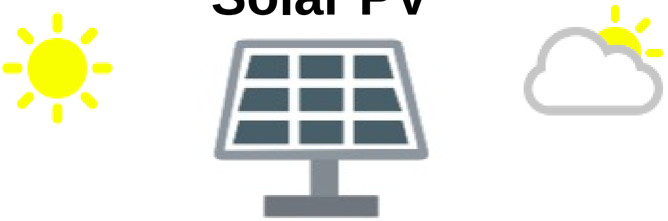
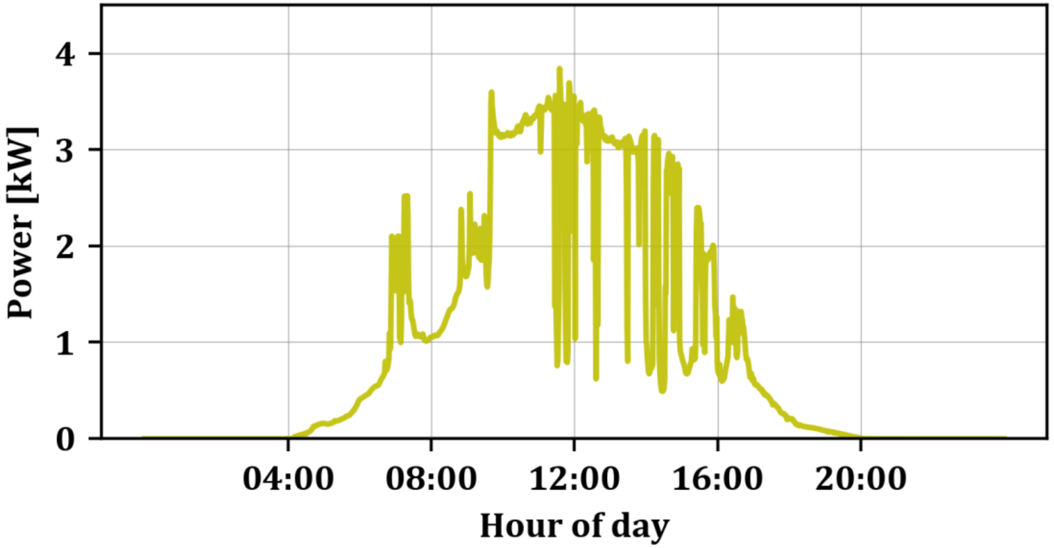
A growing number of **low-carbon technologies (LCTs)** connected to LV networks

Solar PV

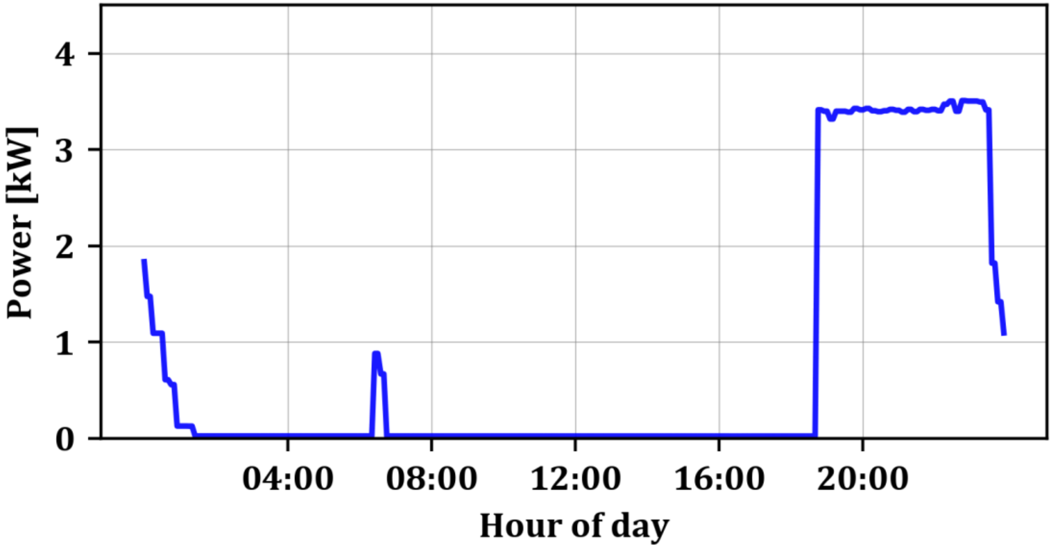


Electric vehicles (EVs)

Solar PV output - 3kW installation - Day 1



EV Charging - Day 1



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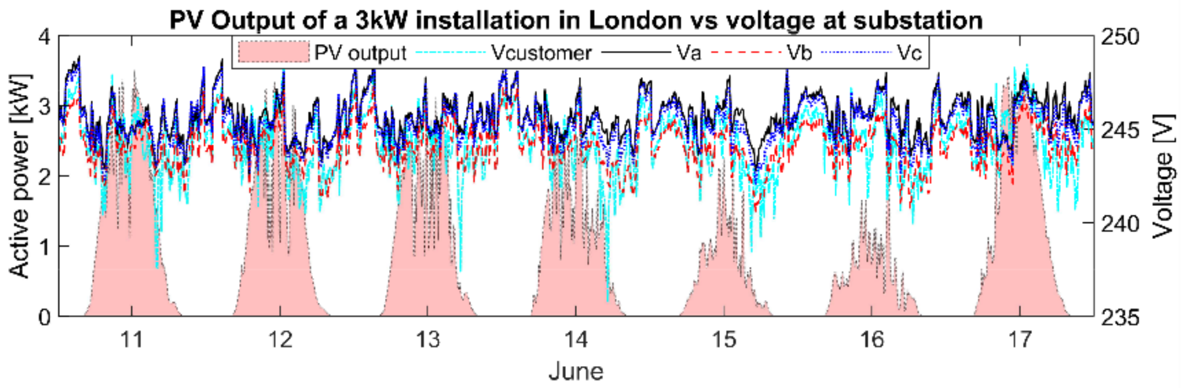
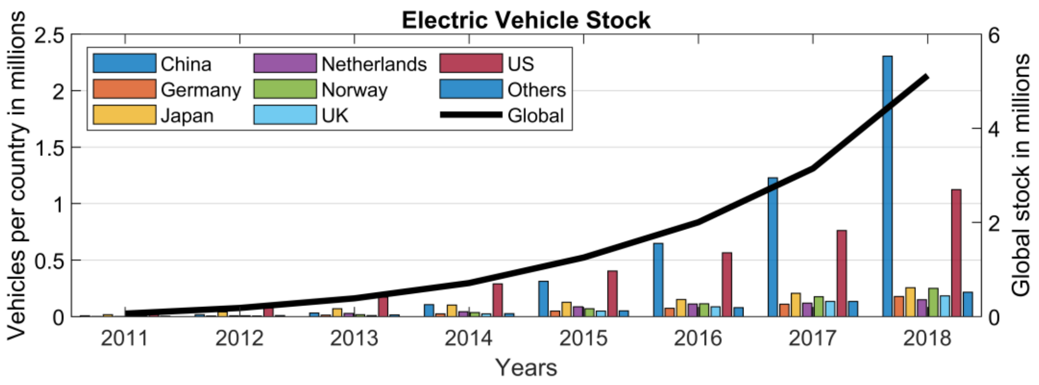
Impacts of distributed generation (DG) and electric vehicles (EVs)

- **Voltage rise** above limits
- Premature ageing of voltage regulation devices
- Increased **energy losses**

- **Voltage drops** in LV feeders
- **Thermal limits** and premature ageing of cables/transformers [1]
- **Congestion** of the network



PV output of 3kW installation in London [2]



EV global stock [3]

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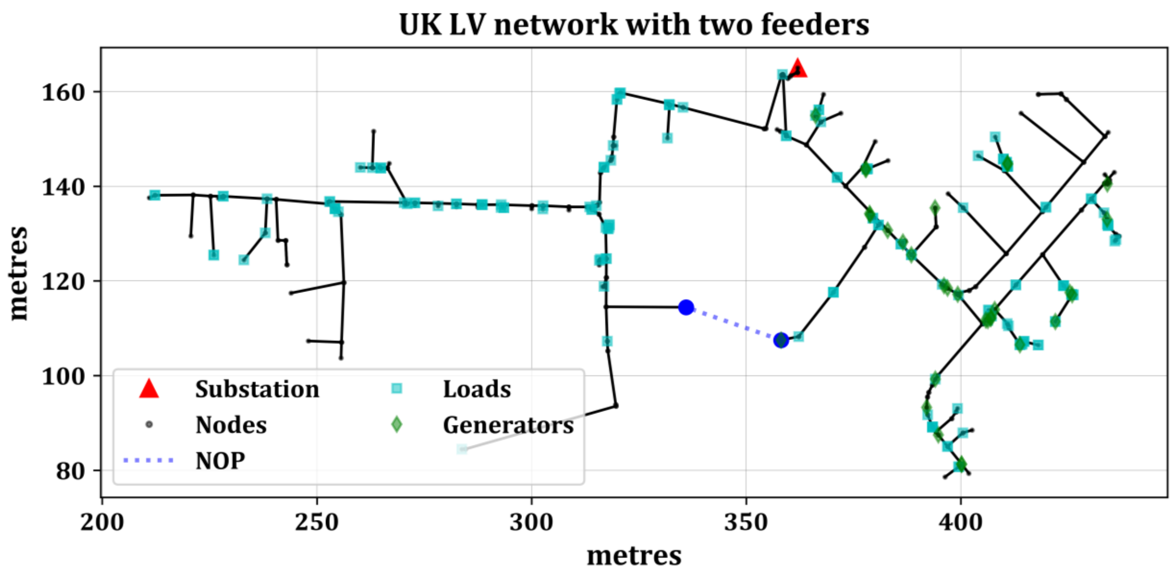
Hosting capacity: the amount of power (DG, EVs) that can be installed along a feeder without violating an operational limit (e.g. voltage, thermal) [4].

Main factors affecting the hosting capacity:

- X:R ratio
- Length of the feeders
- Location of the loads/DG
- Presence of voltage regulators



Different ways to increase the hosting capacity to connect more DG, EVs:

- Network reinforcement/upgrade ✘
- Energy storage ✓
- Demand response ✓

But, how do we **use the existing infrastructure more efficiently?**

- **Active Network Management ?**

2. Active Network Management

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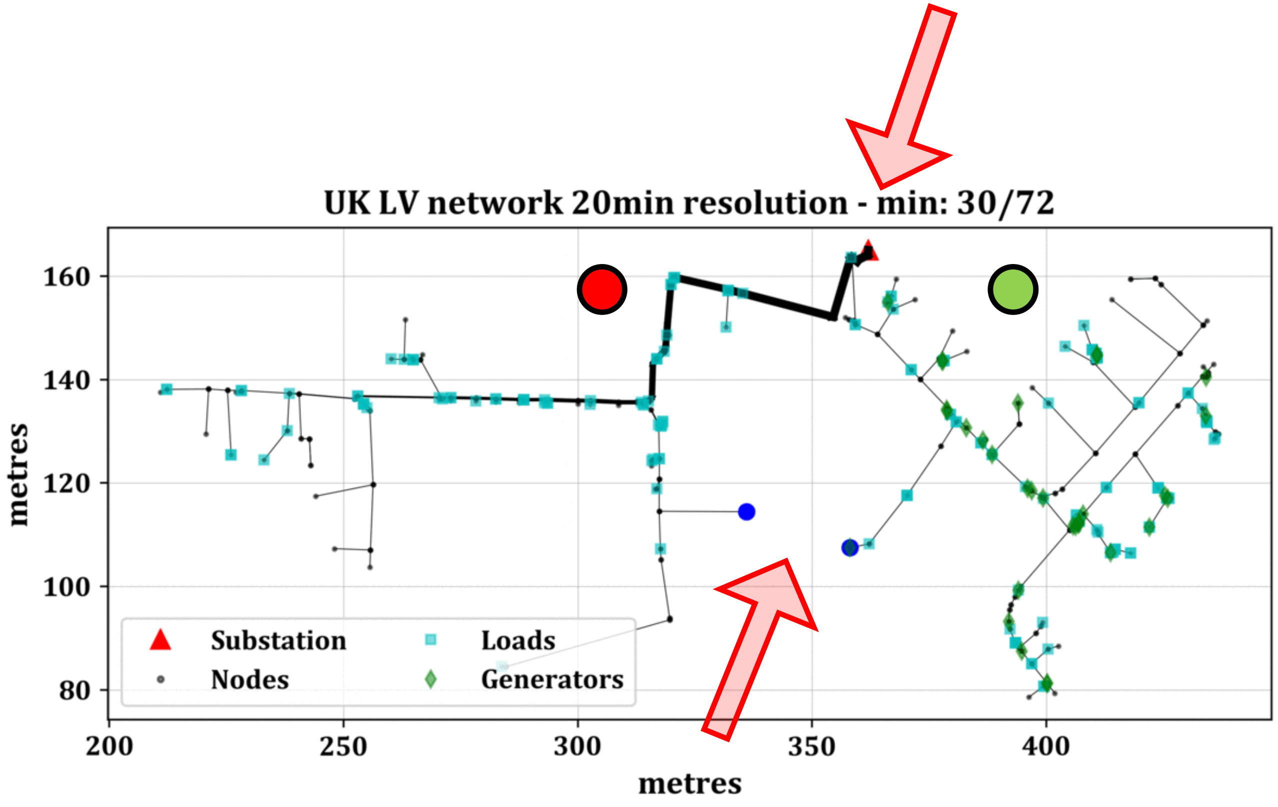
Active network management

- LV networks are **typically congested at some points** whilst **underutilised at others**
- ANM enables **a more efficient distribution of the power flows**
- Moving power flows from highly loaded feeders and transformers **to underutilised parts of the network**
- Releasing **latent capacity**
- Reducing **power losses**



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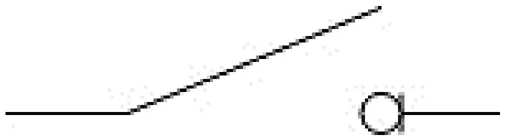
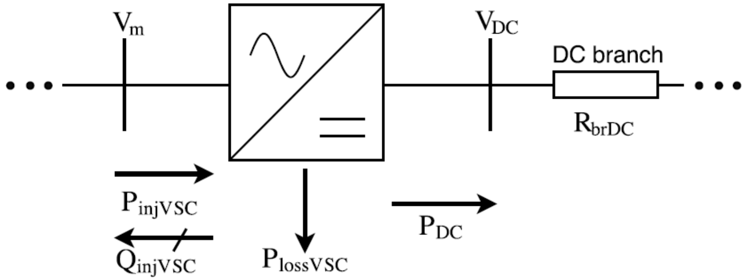
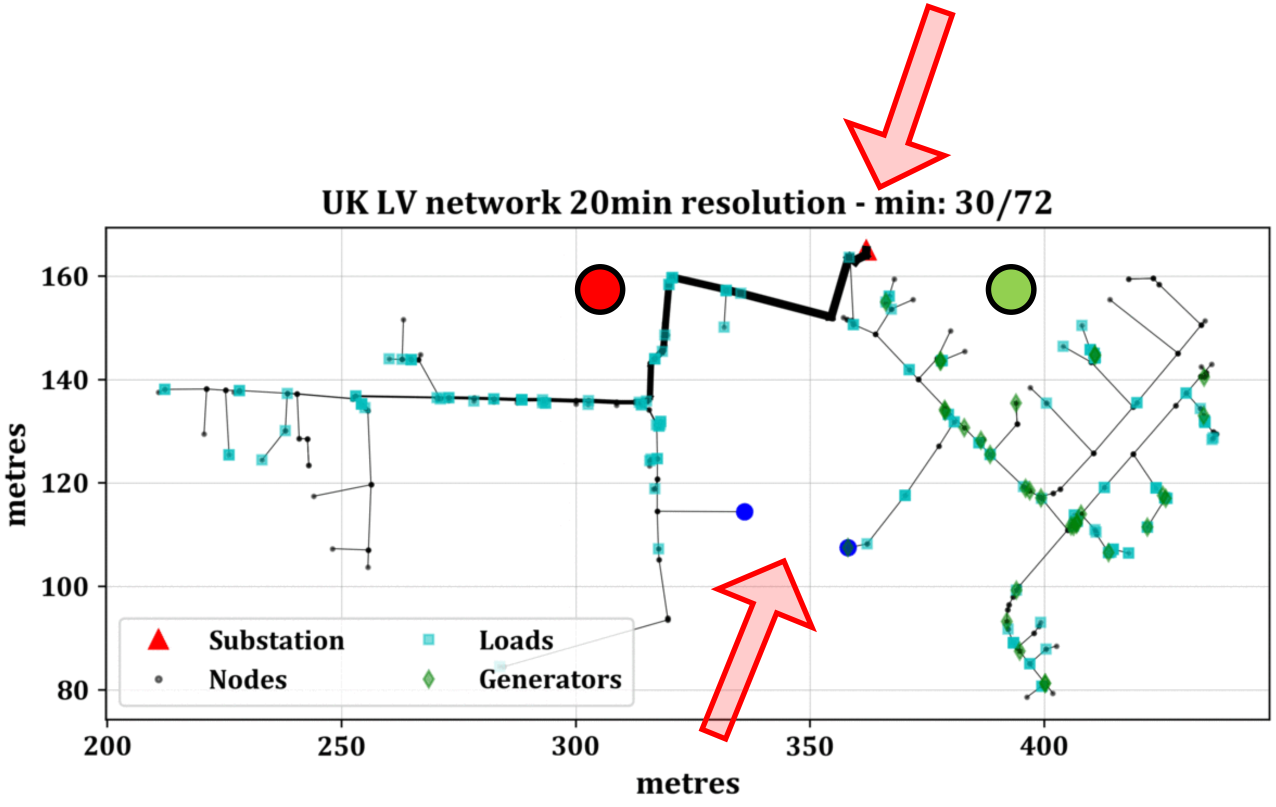
Active network management

A. Network reconfiguration **through switching**



B. Using **power electronic converters**

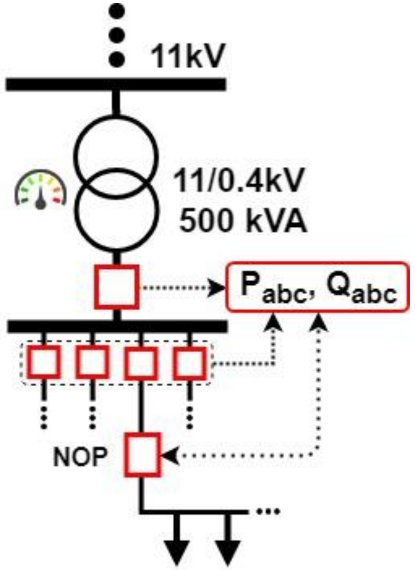


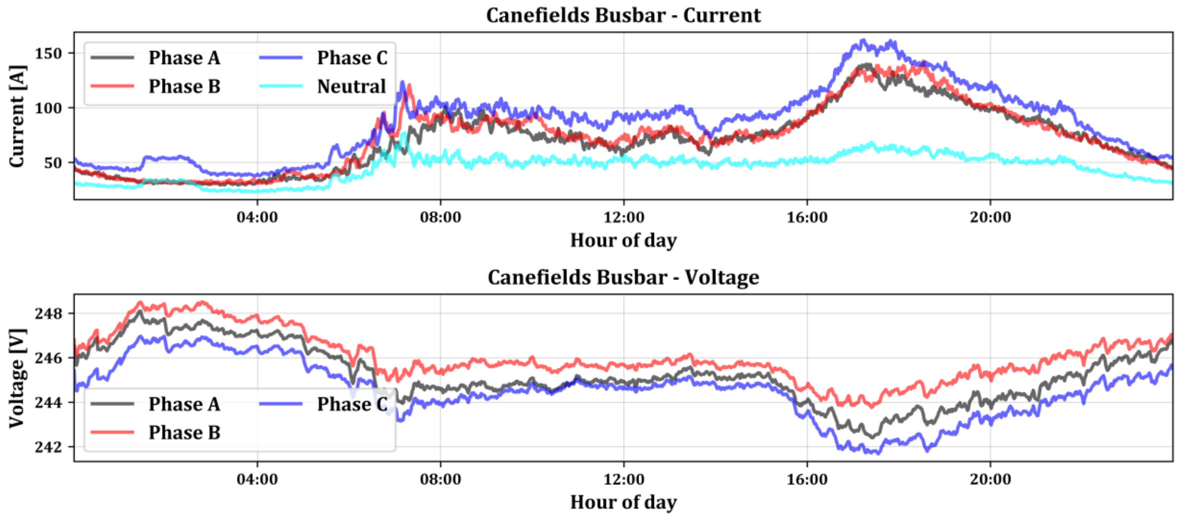


3. OpenLV project

The **OpenLV project**, jointly developed by EA Technology and Western Power Distribution (WPD), installed **monitoring devices at LV substations [5]:**

- Provide both consumers and the network operator with **demand data of their local substation** and also **more than 80 LV substations**
- **Develop and deploy apps** that benefit both the consumers and the operator





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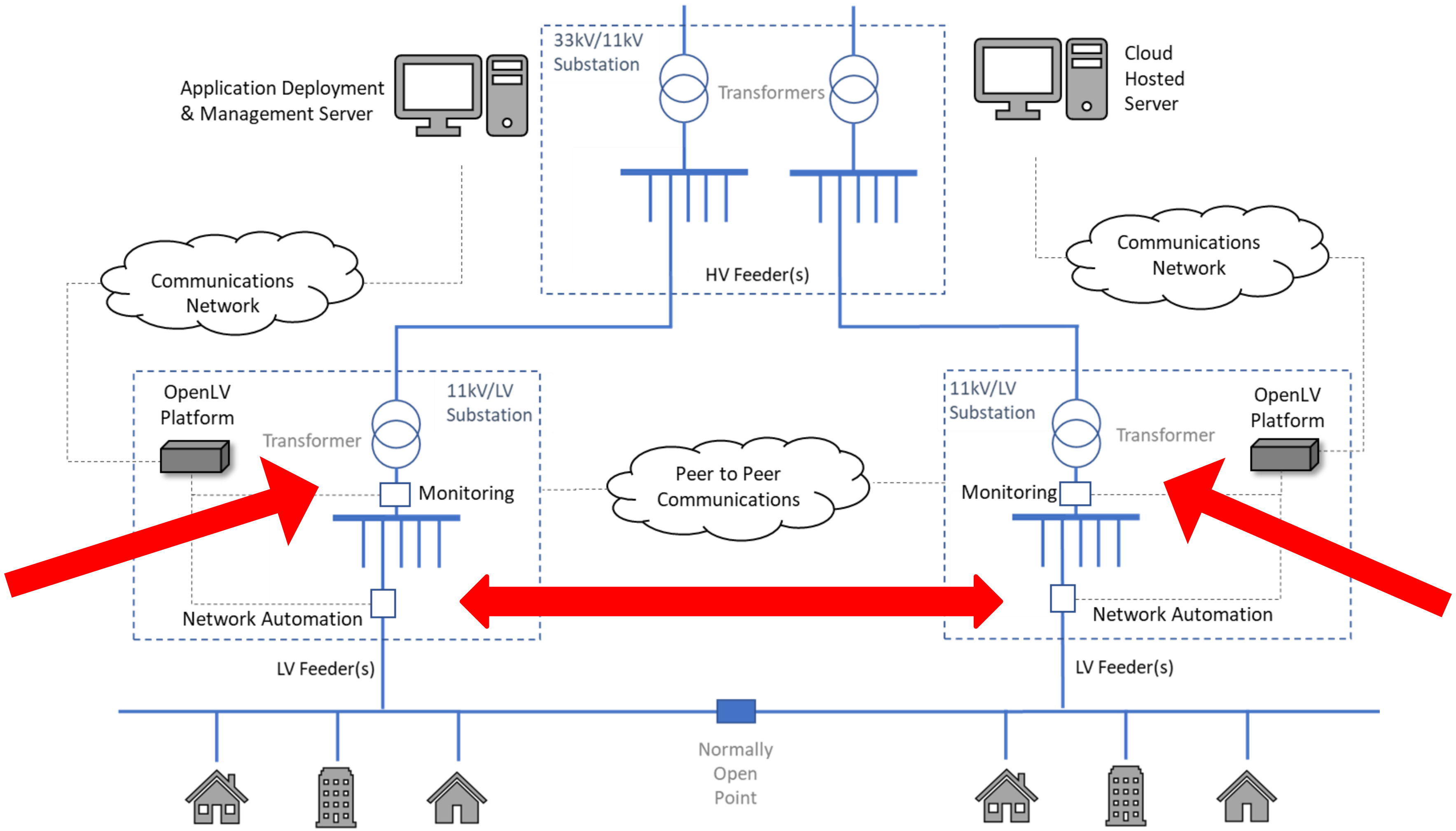
ANM implemented in the OpenLV project via ALVIN Reclose™ units (diagram provided by EA Technology [5])



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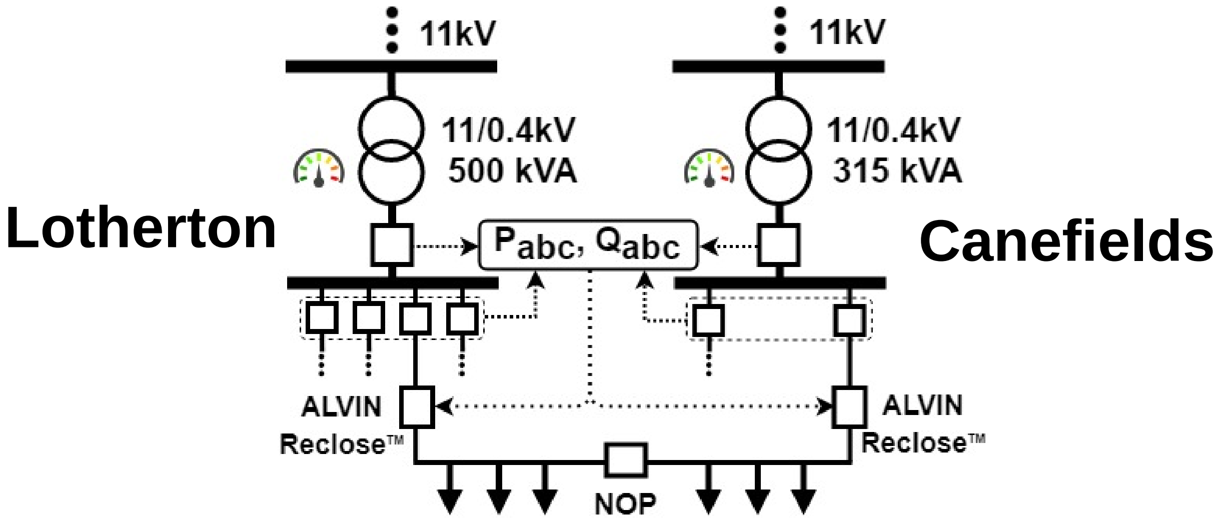
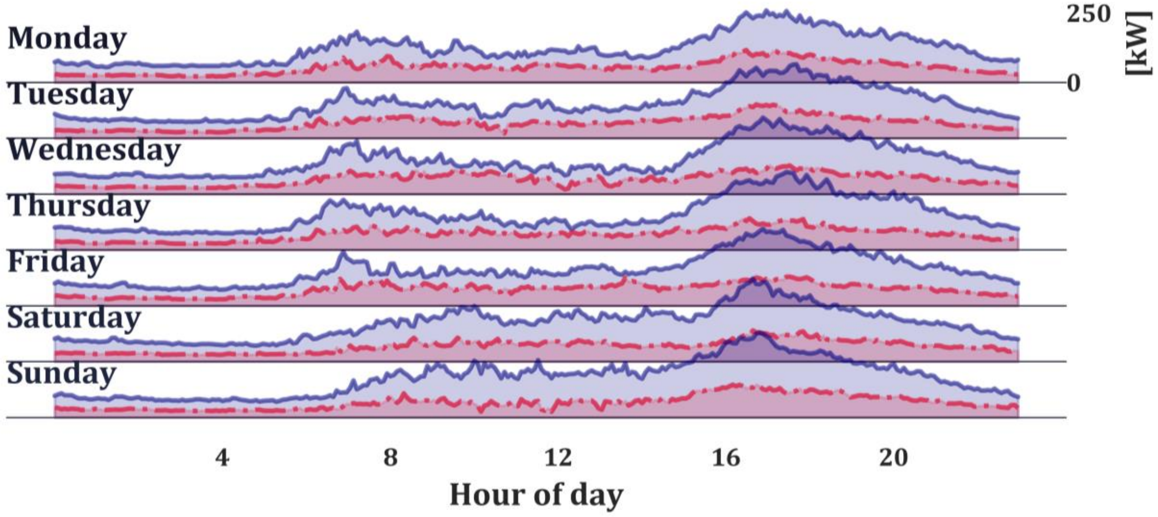
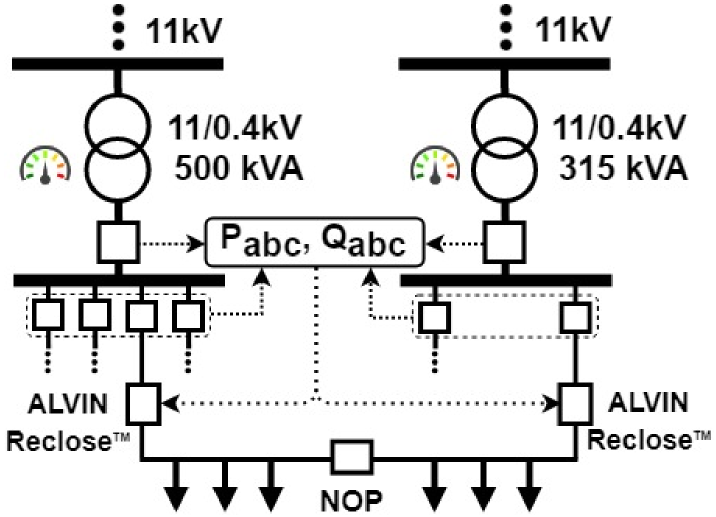
Data from the OpenLV project [5]:

- Provides an accurate estimate of the **loading state of real LV substations**
- Can be used to measure the **degree of phase imbalance** and **power losses**
- Serves as a **benchmark** by allowing the **validation of network models**
- Supports the **analysis of ANM solutions** in real LV networks





How do LV networks they look in reality?



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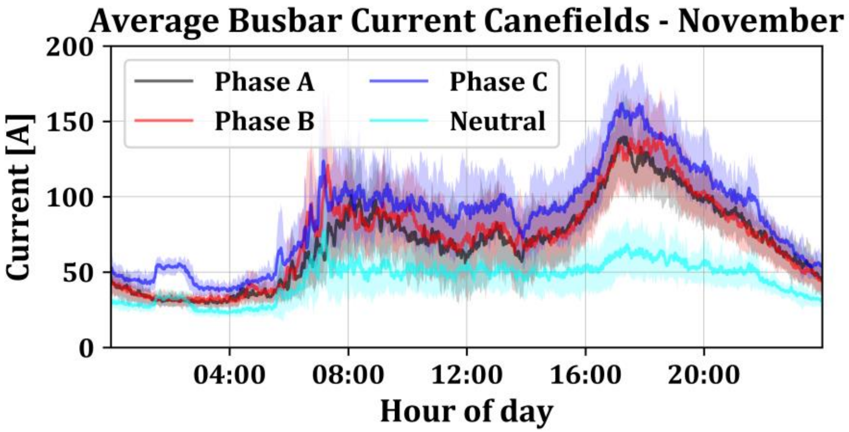
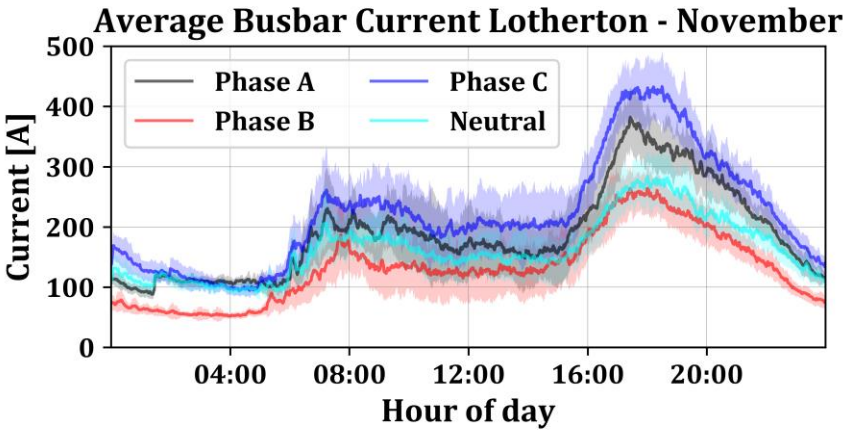
OpenLV historical data available (time-series per phase A, B, C and neutral):

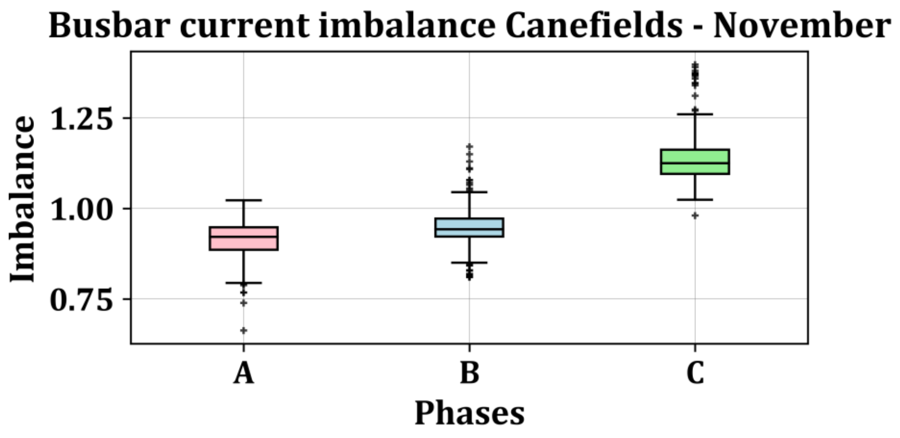
- **1-min** measurements at **busbar** (**voltage** [V], **current** [A], **power** [W])
- **1-min** measurements of **outgoing feeders** supplied by busbar (**voltage** [V], **current** [A], **power** [W])
- **30-min** measurements of **temperatures** outside/inside substation and temperature of **transformer** (a measurement of its loading)

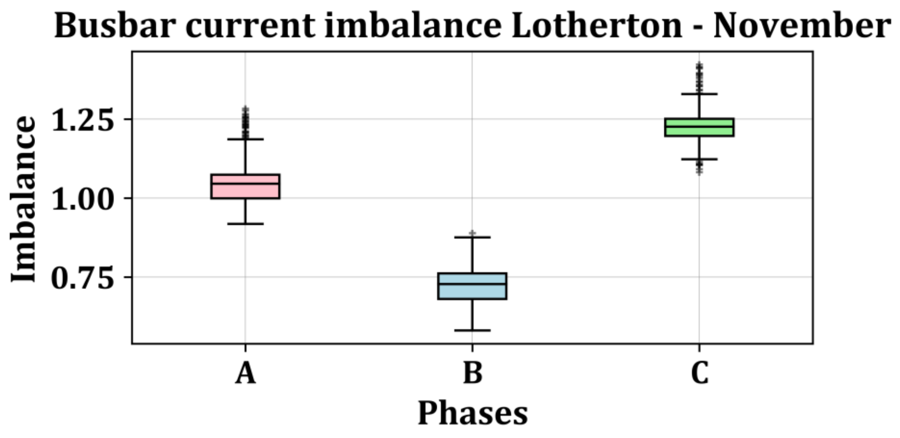




Phase imbalance

- Loads and LCTs are **unevenly distributed across the phases**
- **Imbalance** -> Ratio between **individual phase currents and the average** of the three phases (i.e. a balanced system would be centred at 1 for all phases)
- Imbalance increases the probability of **thermal violations** and **power losses**
- Both LV substations display a **moderate degree of imbalance**





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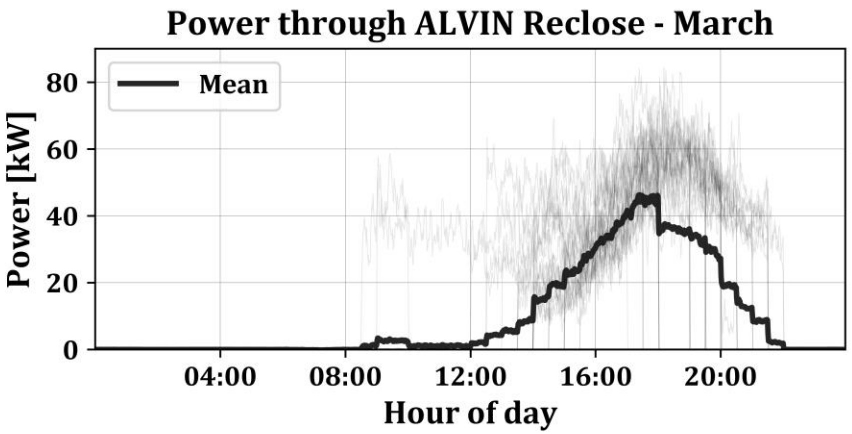
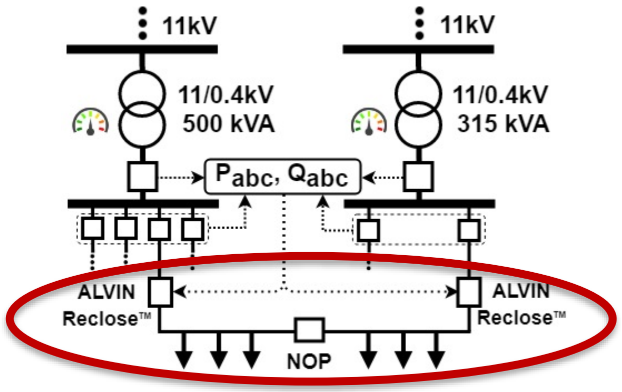
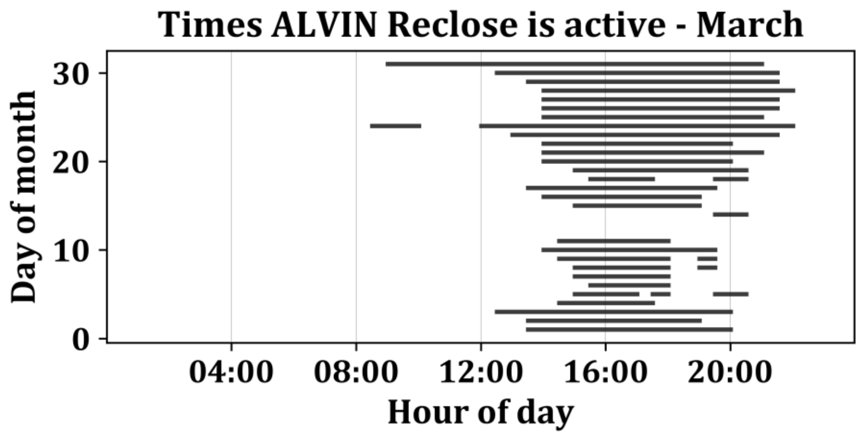
ANM using ALVIN Reclose™ units

- Canefields and Lotherton substations can be **meshed via a NOP using ALVIN Reclose™ units to share their respective loading**
- ALVIN Reclose™ units can **operate autonomously based on the measurements** at the substation and using a loading forecasting **algorithm**
- **Depending on the transformers load the ALVIN Reclose™ units close/open**







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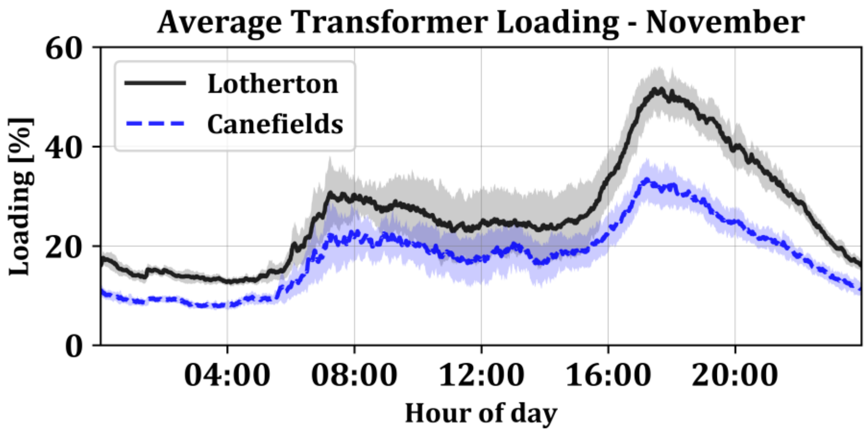
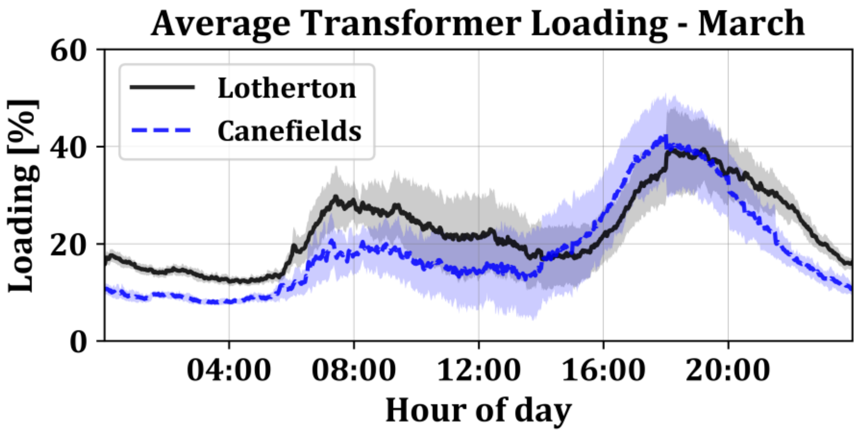
ANM using ALVIN Reclose™ units

- Average **loading profiles for both substations, before (November)** and **after (March)** the ALVIN Reclose™ units entered operation
- **Load is transferred** from the substation with the **highest utilisation (Lotherton)** to the one with **the lowest utilisation (Canefields)**
- Resulting in a **more equalised load distribution between the two substations**





4. Optimal Power Flow

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ANM using power electronic converters

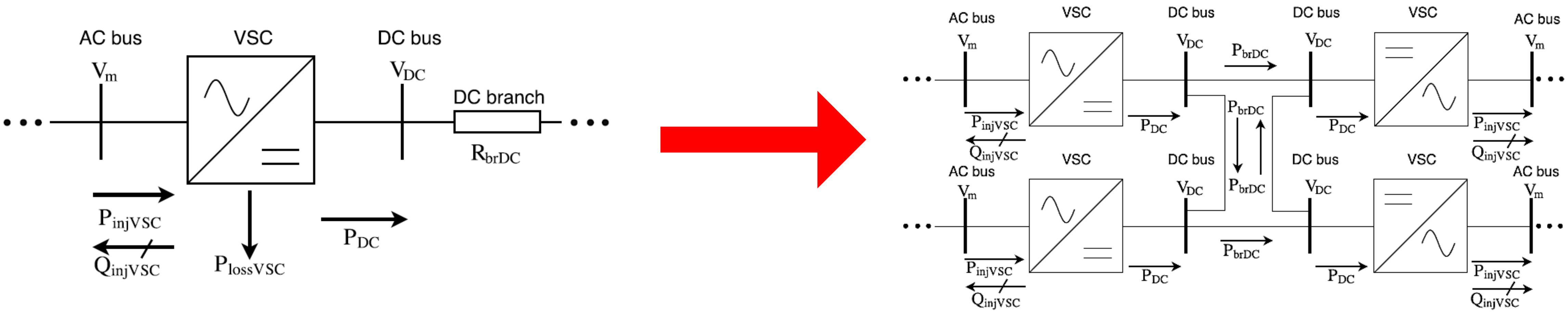
The **typical AC OPF** is used to calculate the **optimal set points** for generators and regulating devices to meet a specific objective, subject to operational constraints [6].

$$
\begin{aligned}
\min_{X} \quad & f(x) = \sum_{i=1}^{N} f_i(P_{gi}) \\
\text{s.t.} \quad & P_{g,i} - P_{d,i} - P_i(V,\theta) = 0, \\
& Q_{g,i} - Q_{d,i} - Q_i(V,\theta) = 0, \\
& P_{g,i}^{min} \leq P_{g,i} \leq P_{g,i}^{max}, \\
& Q_{g,i}^{min} \leq Q_{g,i} \leq Q_{g,i}^{max}, \\
& V_i^{min} \leq V_i \leq V_i^{max}, \\
& P_{br,k} \leq P_{br,k}^{max}
\end{aligned}
$$

- The **power flow equations** and voltage constraints are **non-linear** and **non-convex**
- A **non-linear solver** is needed, such as the Interior Point Method (IPM).

ANM using power electronic converters

- **Voltage source converters (VSCs) connected back-to-back** allow the **transfer of power** to and from individual feeders
- **Active management** and distribution of power flows
- VSCs can be treated as **power injections** at the respective node
- The **set points of the VSCs** can be **calculated via an Optimal Power Flow [7]**



Incorporating the characteristics of the converters into the OPF formulation

- Active **power balance** for each converter:

$$P_{injVSC,i} - P_{lossVSC,i} - P_{DC,i} = 0$$

- **Power losses** of the converter as a quadratic expression, representing the **no-load, switching and conduction losses** of the converter, respectively [8]:

$$P_{lossVSCi} = a_i + b_i I_k + c_i I_k^2$$

- Power flows **between converters via DC connections:**

$$P_{DC,i} = V_{DC,i} \sum_{j=1}^{N} V_{DC,j} [G_{DC,i,j}]$$

5. Case study

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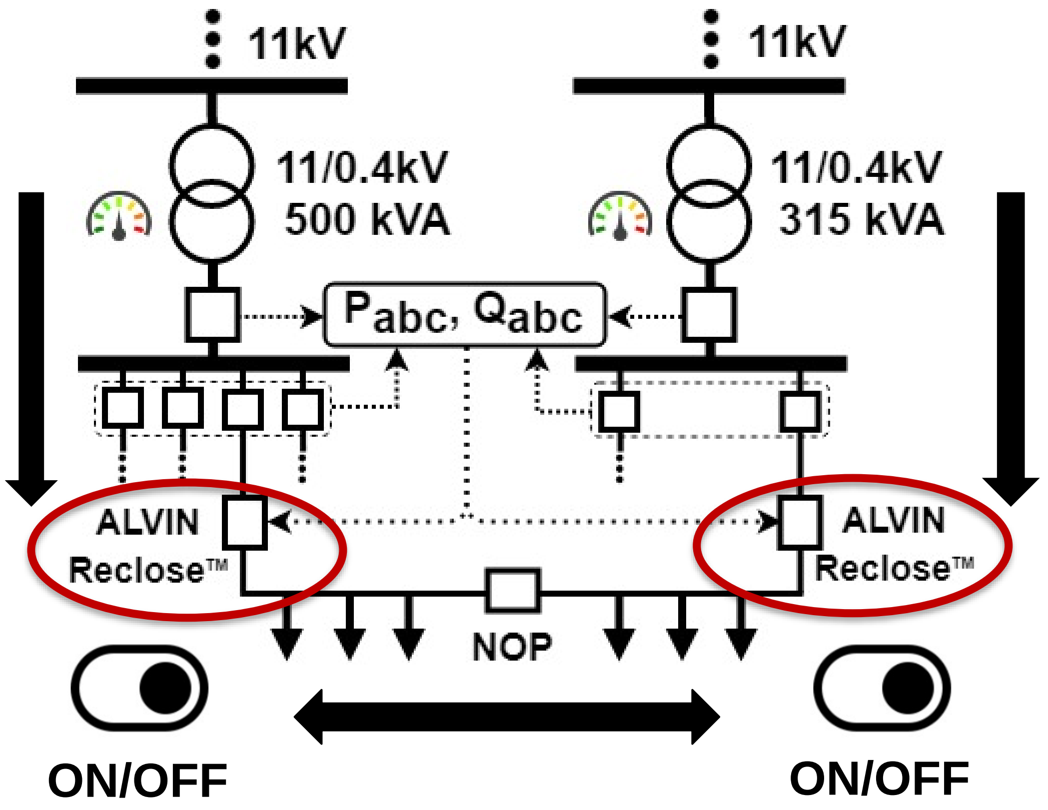
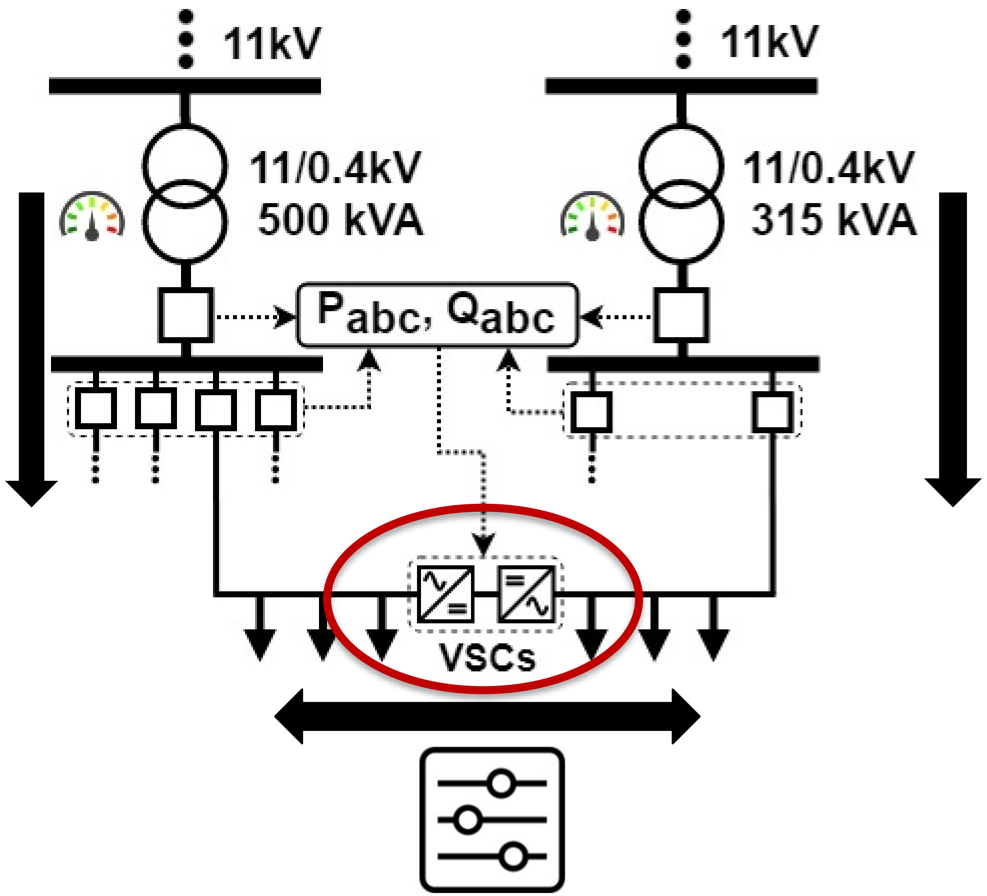
ANM using ALVIN Reclose™ units



ANM using power converters



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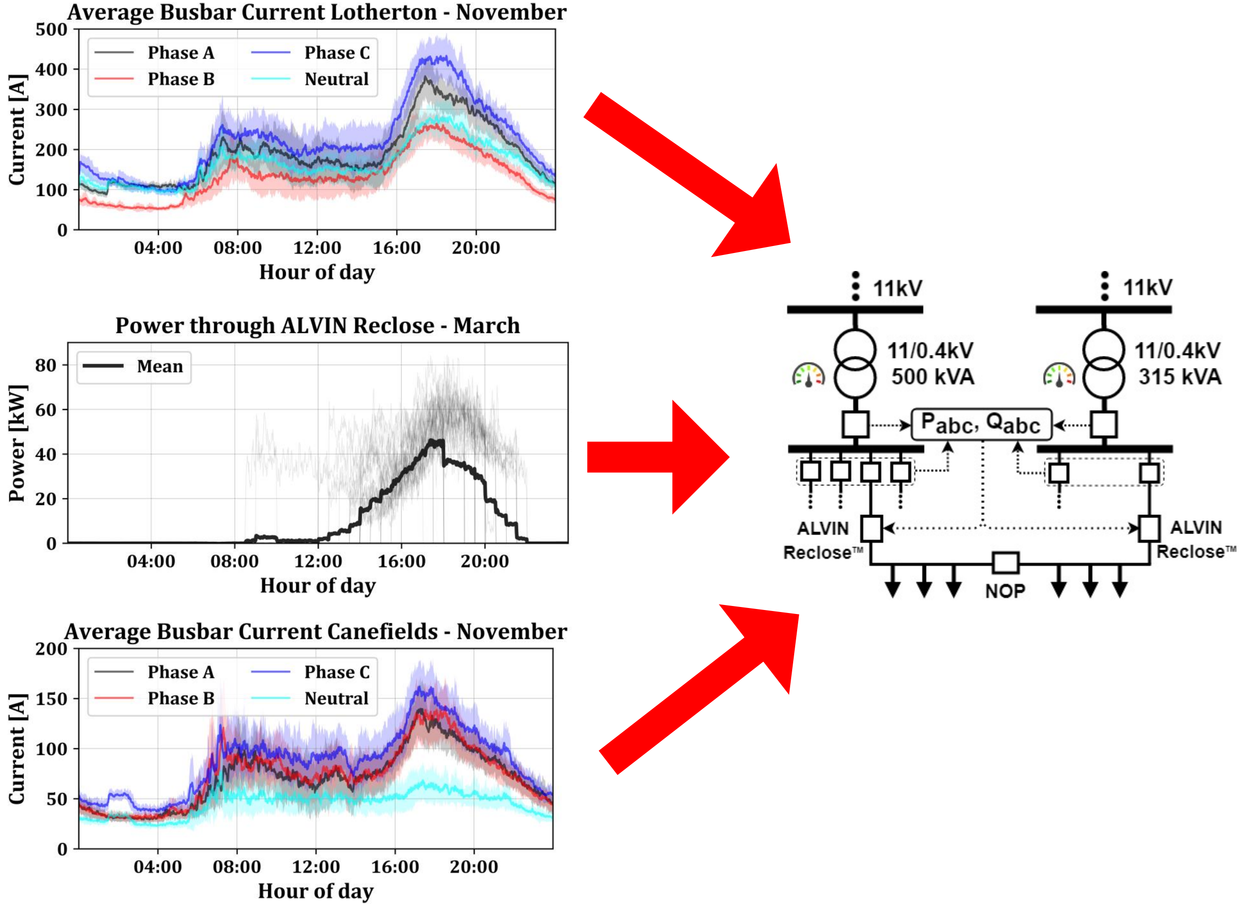
Comparing both ANM schemes

A. ANM using ALVIN Reclose™ units
B. ANM using power converters

- Network **data from the OpenLV project will be used as input** for the case-study.

- A **three-phase model of the feeders is built in OpenDSS** [9] using the transformers and cable impedance data.

- The **ANM using power converters can be simulated** on the same base network with the data available and the **OPF.**



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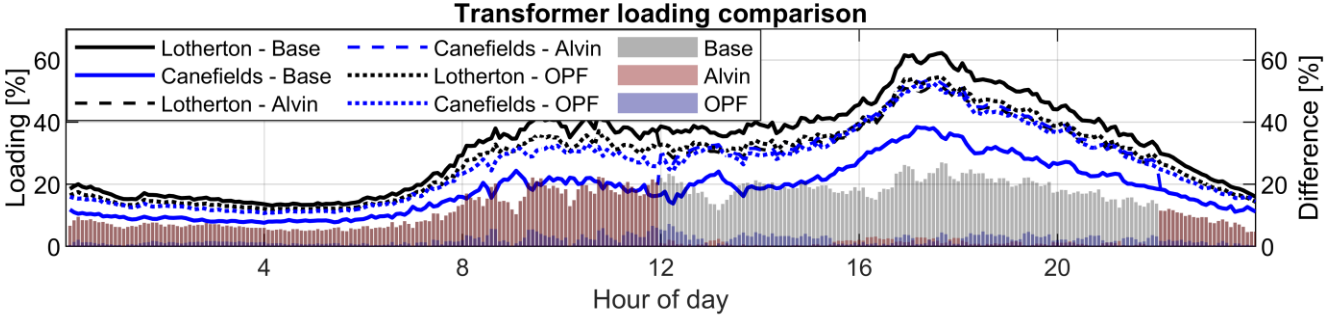
Comparing both ANM schemes

A. ANM using ALVIN Reclose™ units
B. ANM using power converters

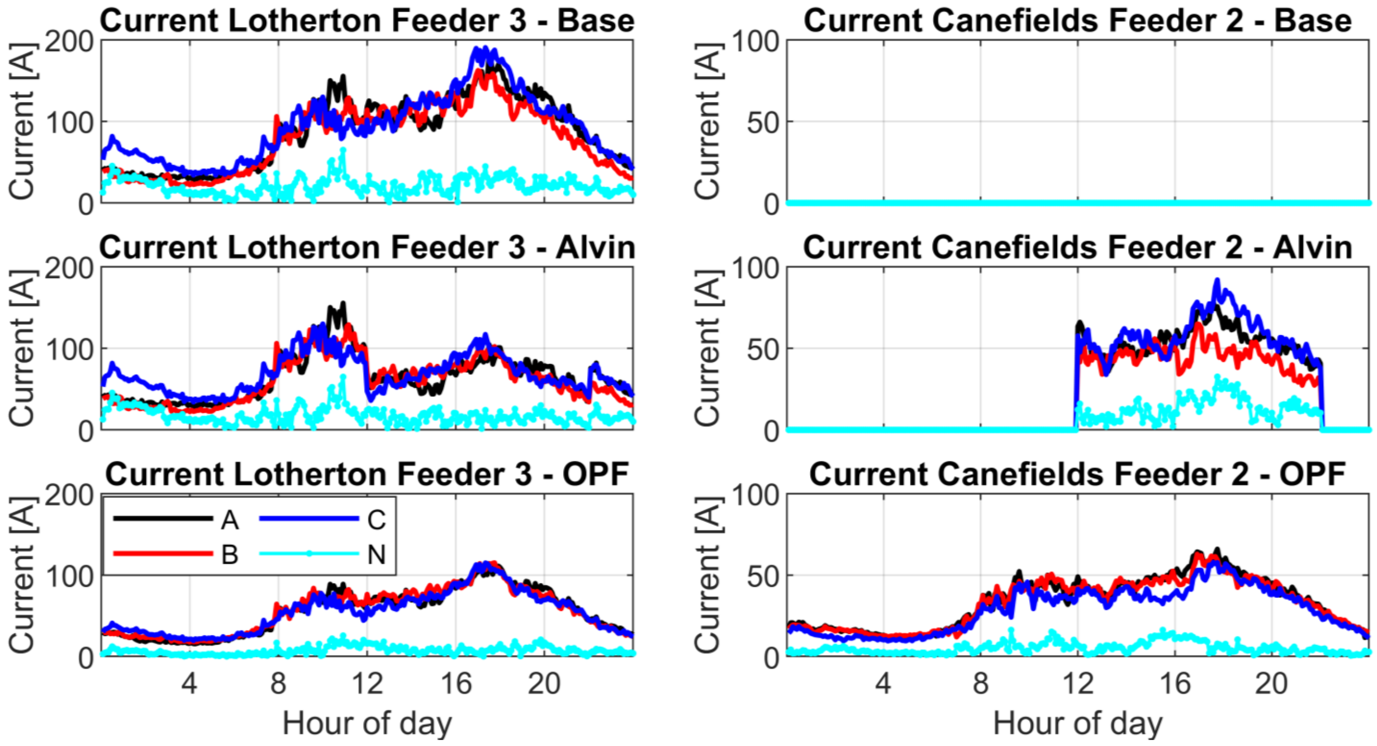
- Comparison of the loading of both transformers throughout the day
- The **converters keep the loading** of the transformers almost **equalised**
- The benefits of the **meshing via ALVIN Reclose™ units are quite close to the optimal settings** obtained by the OPF.



Case	Max power transfer [kW]	Losses network [kWh]	Losses VSCs [kWh]	Tx-1 S max [pu]	Tx-2 S max [pu]
Base	-	80.08	-	0.623	0.384
Alvin	22.67	78.04	-	0.516	0.541
OPF	16.97	77.11	35.56	0.544	0.529
OPF Eq	18.10	77.53	40.63	0.536	0.536

Comparing both ANM schemes

- Current flows through Feeder 2 at Canefields **once the ALVIN Reclose™ unit is closed.**
- A large difference between the current transferred via the ALVIN Reclose™ unit and the converters.
- **Load is transferred from Lotherton to Canefields,** lowering the peak loading of Lotherton.
- The **power transfer and the overall current profile are more balanced**



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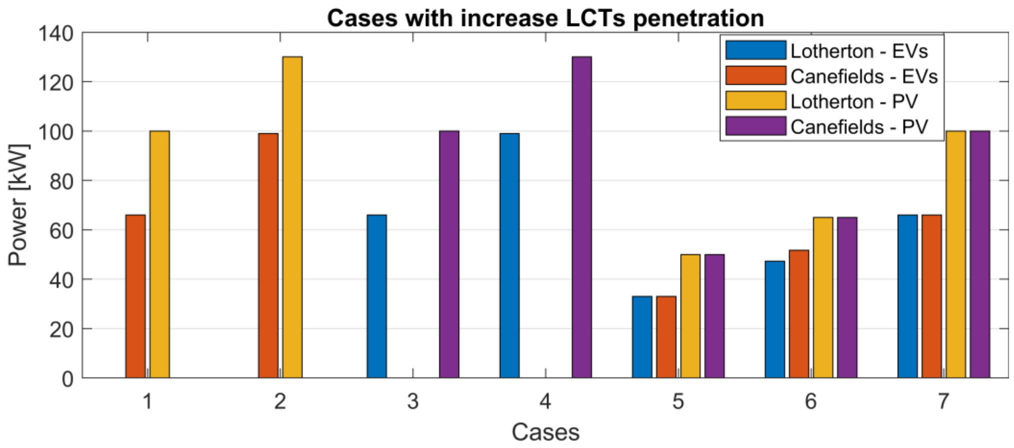
Comparing both ANM schemes with increased levels of LCTs

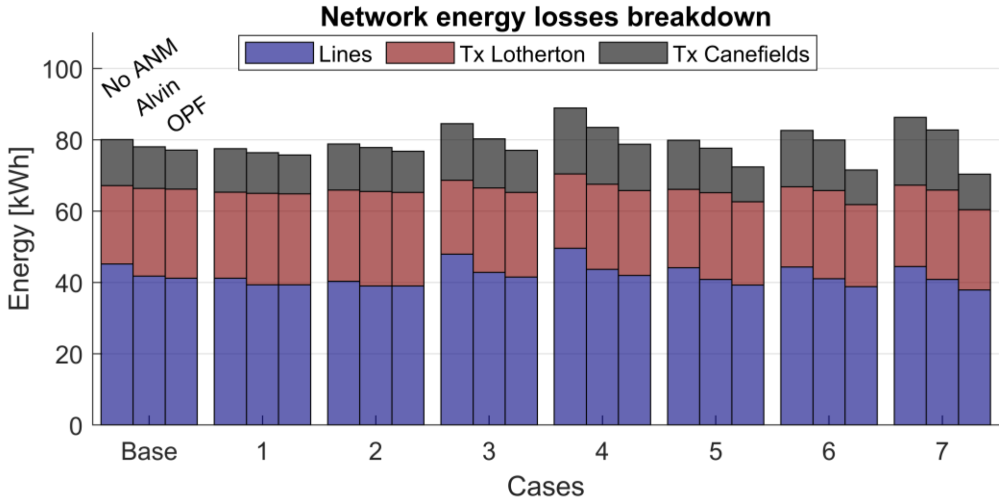
- The long-term viability of both approaches depends on their **performance when dealing with the high variability of LCTs.**

- Only small **solar PV and EVs** are be considered, as these are the **two most common LCTs installed in LV networks.**

- The **power losses are affected by the specific location** of the LCTs.

- The **optimal distribution of the powers might be different** from the one determined by the **network parameters.**





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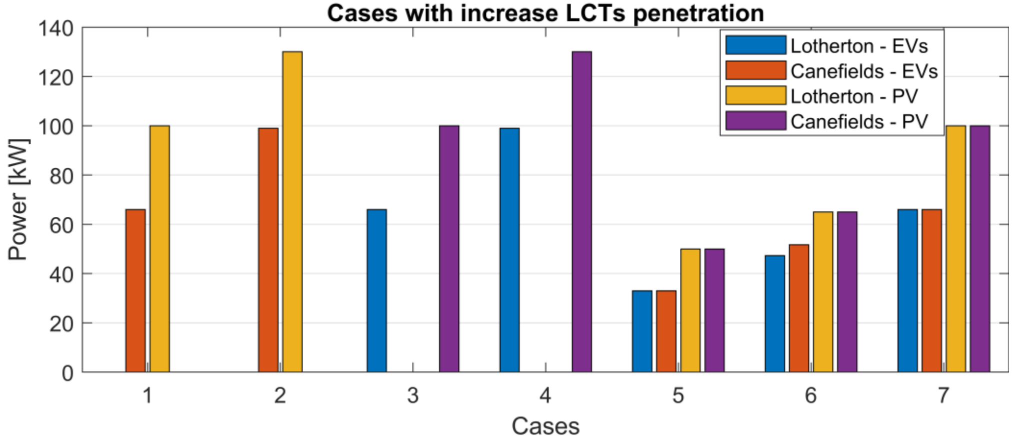
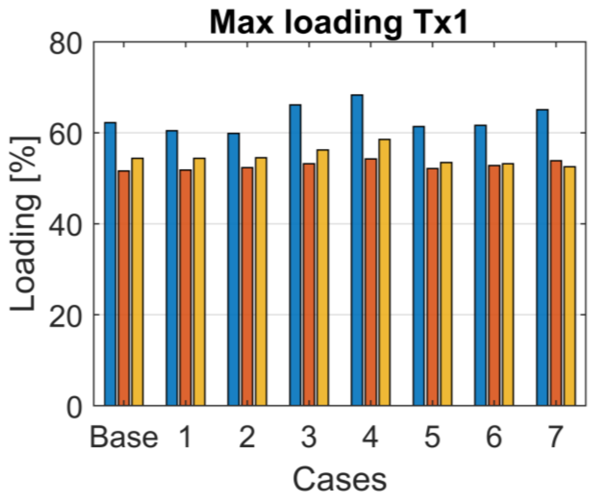
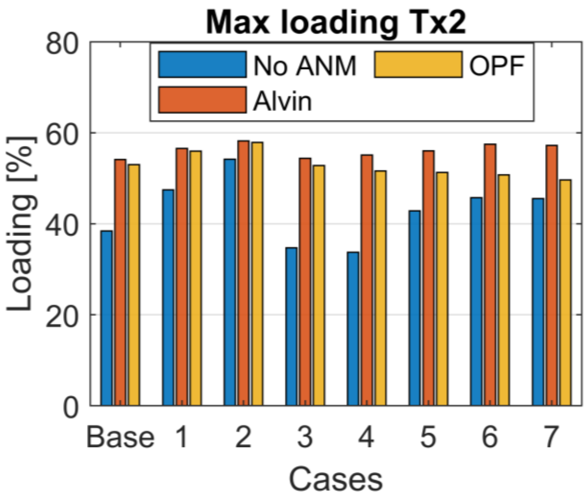
Comparing both ANM schemes with increased levels of LCTs

- As the **amount of LCTs increases,** the performance of **the approach using ALVIN Reclose™ falls behind** compared to the converter-based strategy.
- The **maximum loading of transformer 1 is decreased substantially** in both cases, when compared to the base case.
- The **ANM with converters** result in the **lowest overall loading for both transformers**







6. Conclusions

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ANM using ALVIN Reclose™ units

- **Simple control strategy** allows autonomous operation **based on measurements and forecasting** algorithm.
- Limited flexibility due to a **reduced number of possible open/close** switch commands.
- **Cannot be used to reduce the phase imbalance** within feeders.
- The ALVIN Reclose™ units **do not suffer additional power losses.**

ANM using power converters

- Requires a **complex control scheme** to calculate the converter power set points, **such as an OPF.**
- The converters allow **a full control over the power injections**, can **balance power flows between phases.**
- The objective function of the converters can be **tailored to reflect the most pressing network constraint.**
- The **power converters incur in additional power losses** when transferring power.

- **LV networks will become saturated at particular substations and feeders**
- **Active management of the power flows** will become essential **to enable a more efficient distribution of the power** between feeders/substations
- The approach **based on ALVIN Reclose™ units leads to benefits that are close to the optimal settings obtained by the OPF**
- The optimal power distribution **can differ substantially from case to case** and might not be achieved by simply reconfiguring the network.
- **Meshing with power converters has additional benefits, it can be adapted to specific needs (control flexibility)** and it can **reduce phase imbalance**

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Acknowledgment

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Thank you for your attention

Questions?

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