Pointing out the Convolution Problem of Stochastic Aggregation Methods for the Determination of Flexibility Potentials at Vertical System Interconnections

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About the Authors

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Motivation – Transformation of Electric Power System

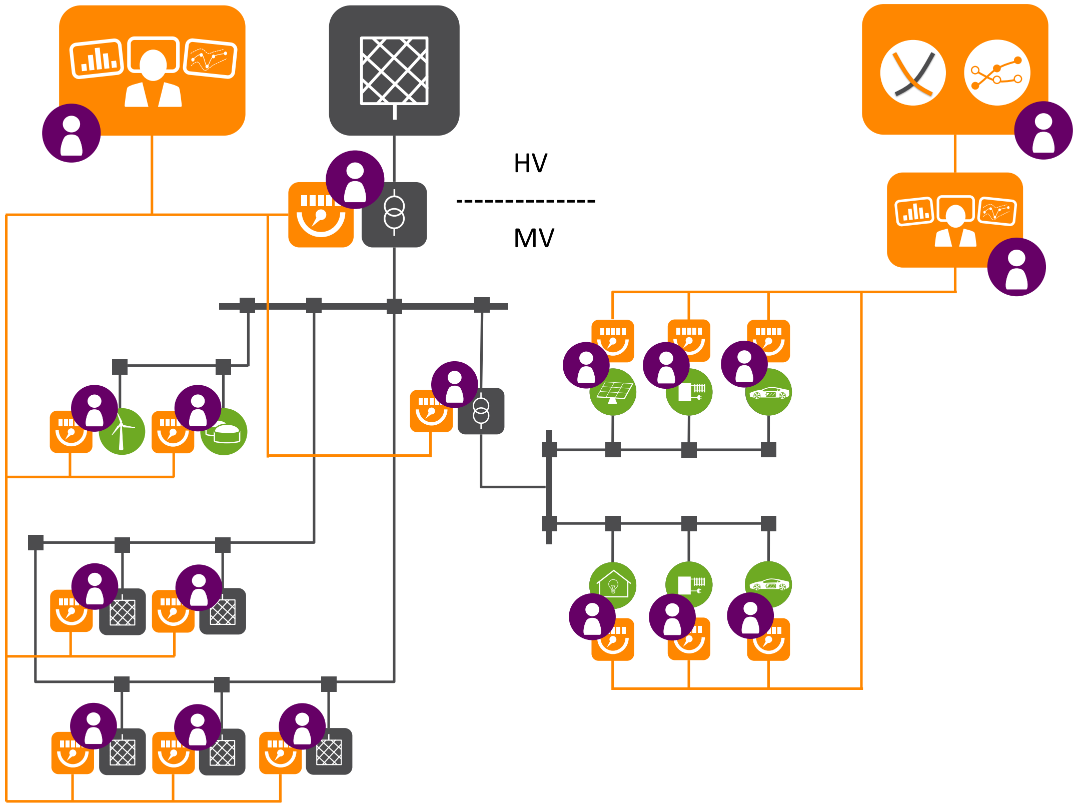
– Massive integration of **DER** into the **distribution grids**

– **Distribution grids** operated closer to their **operational limits**

– Flexible ancillary services for **voltage maintenance** or **power balancing** from **DER**

– Risk of **conflicting** or counteracting use of **flexibility options**

→**Coordination** between **grid operators** has to be **strengthened**



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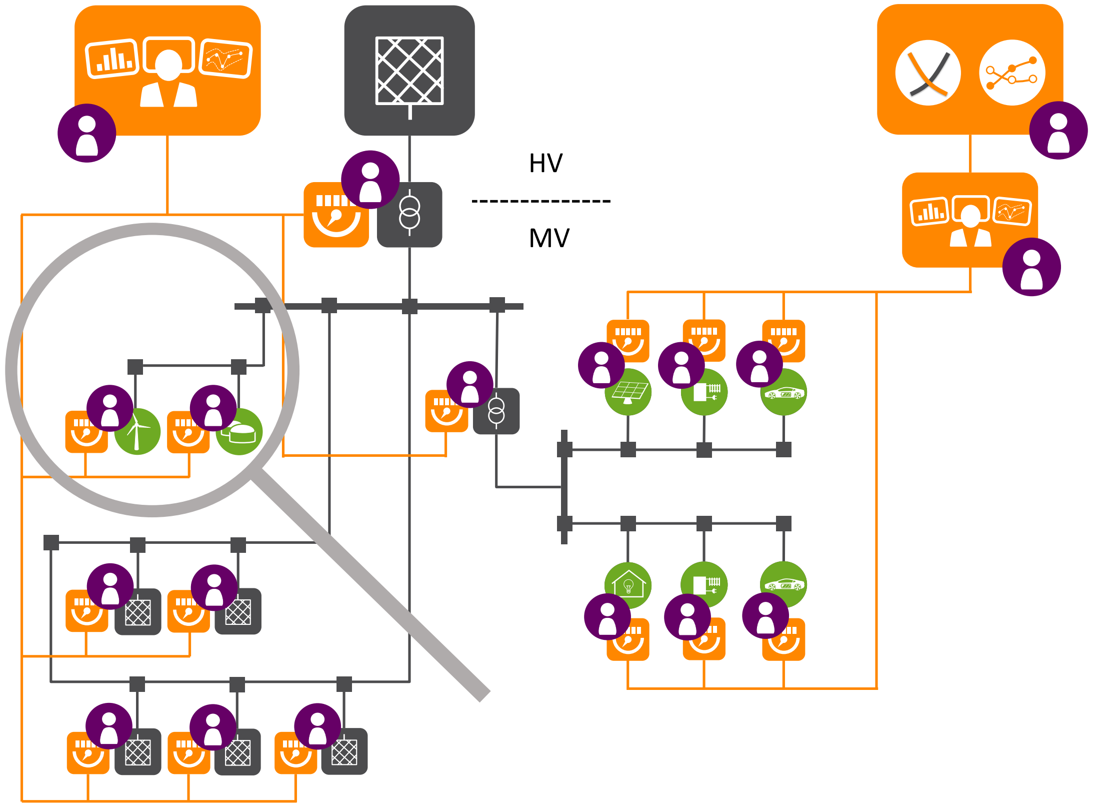
Conflicting Use of Flexibility Options – Examples



Conflicting Use of Flexibility Options – Examples

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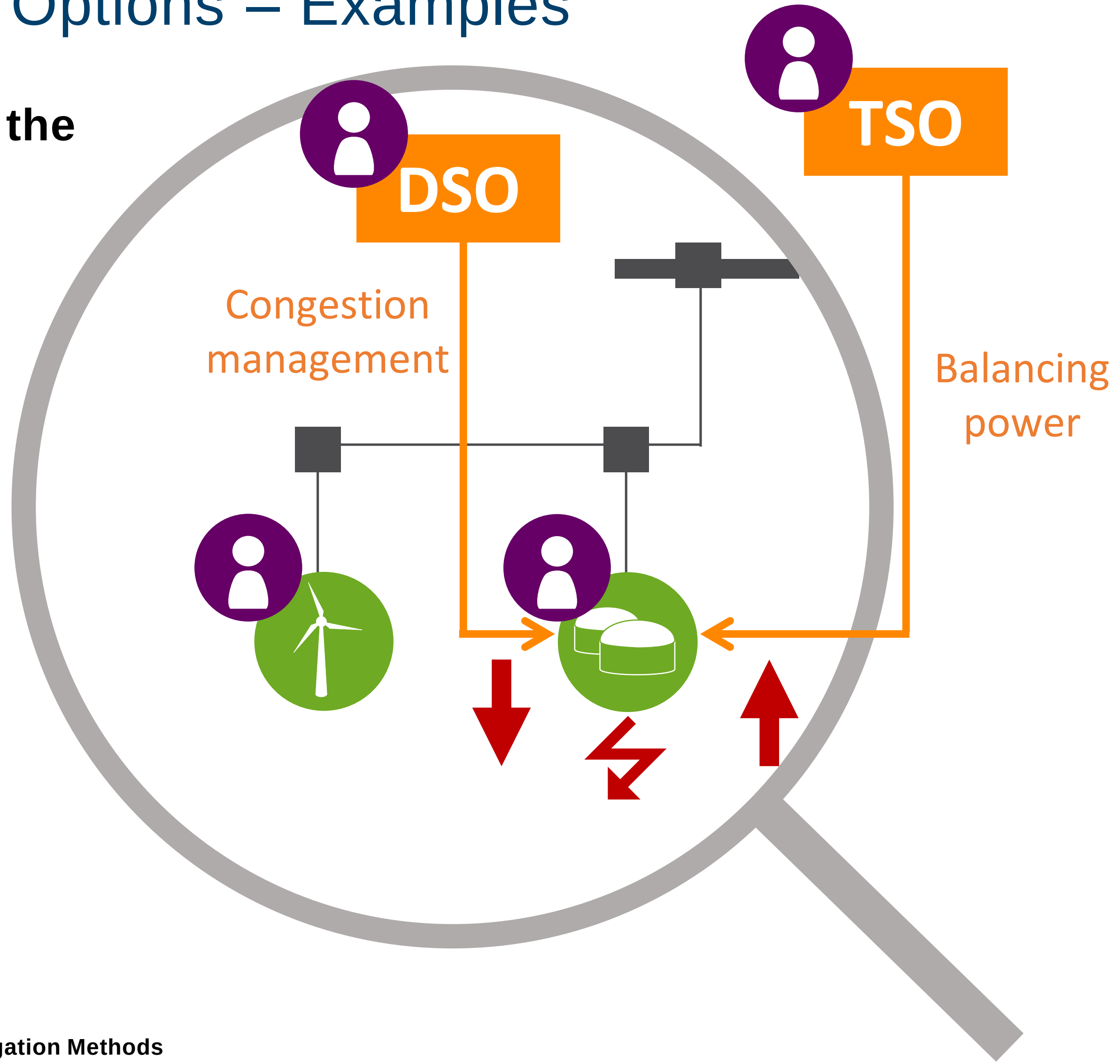
Conflicting Use of Flexibility Options – Examples

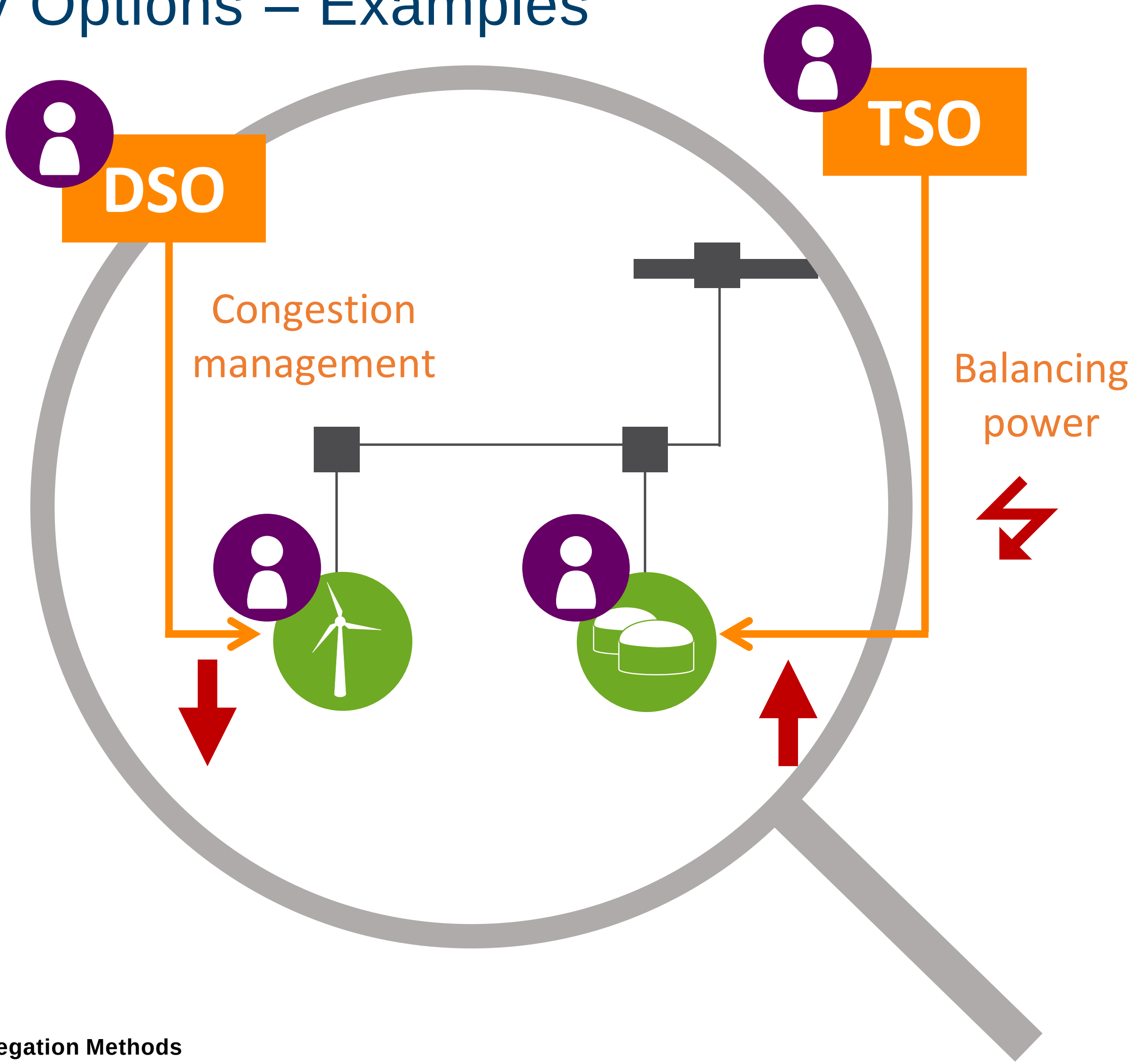
- **Conflicting control set-points for the same DER from different stakeholders**



Conflicting Use of Flexibility Options – Examples

- Conflicting control set-points for the same DER from different stakeholders

- **Control set-point for one DER triggers opposite control action on other DER(s)**



Conflicting Use of Flexibility Options – Examples

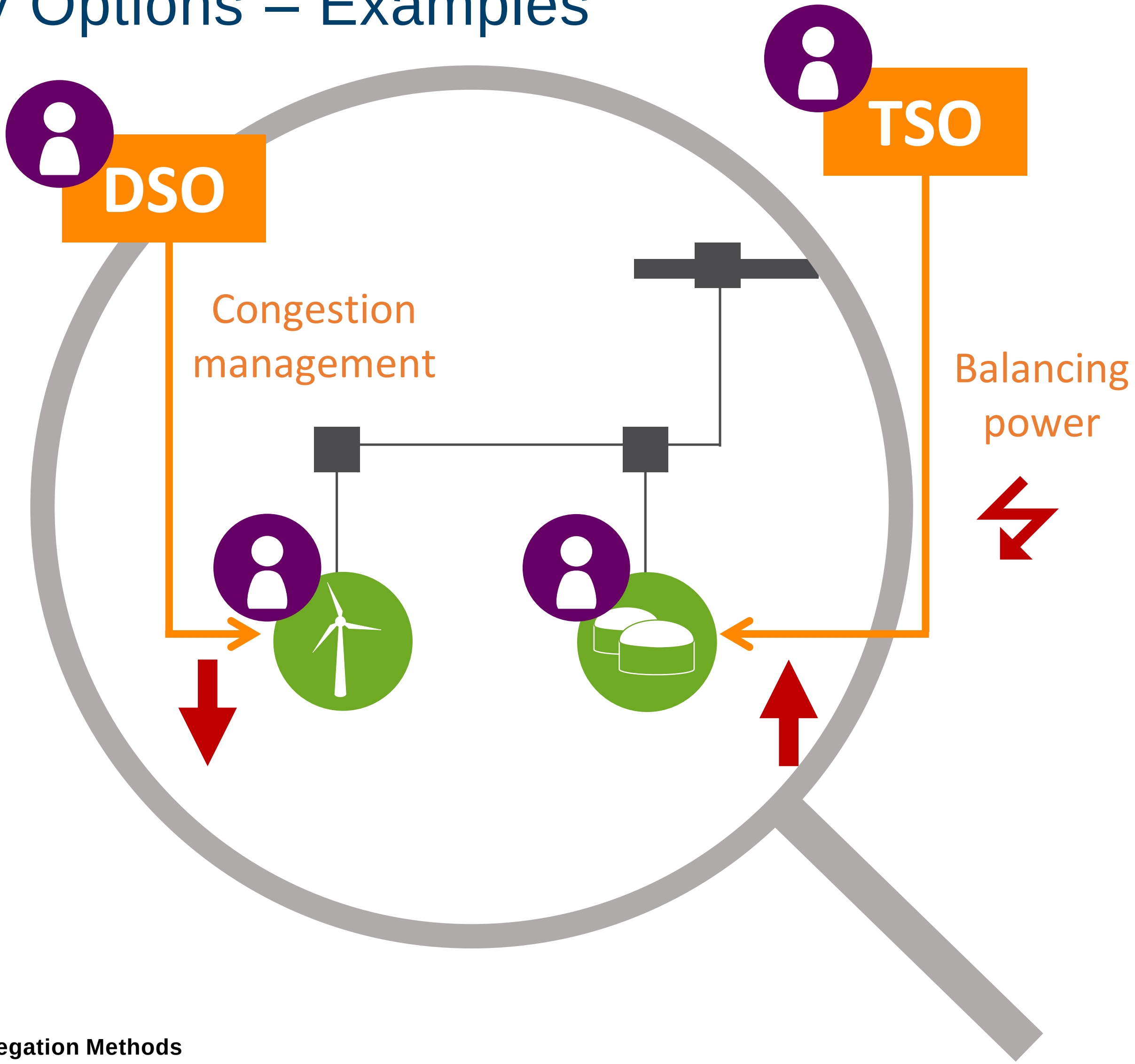
– Conflicting control set-points for the same DER from different stakeholders

– Control set-point for one DER triggers opposite control action on other DER(s)

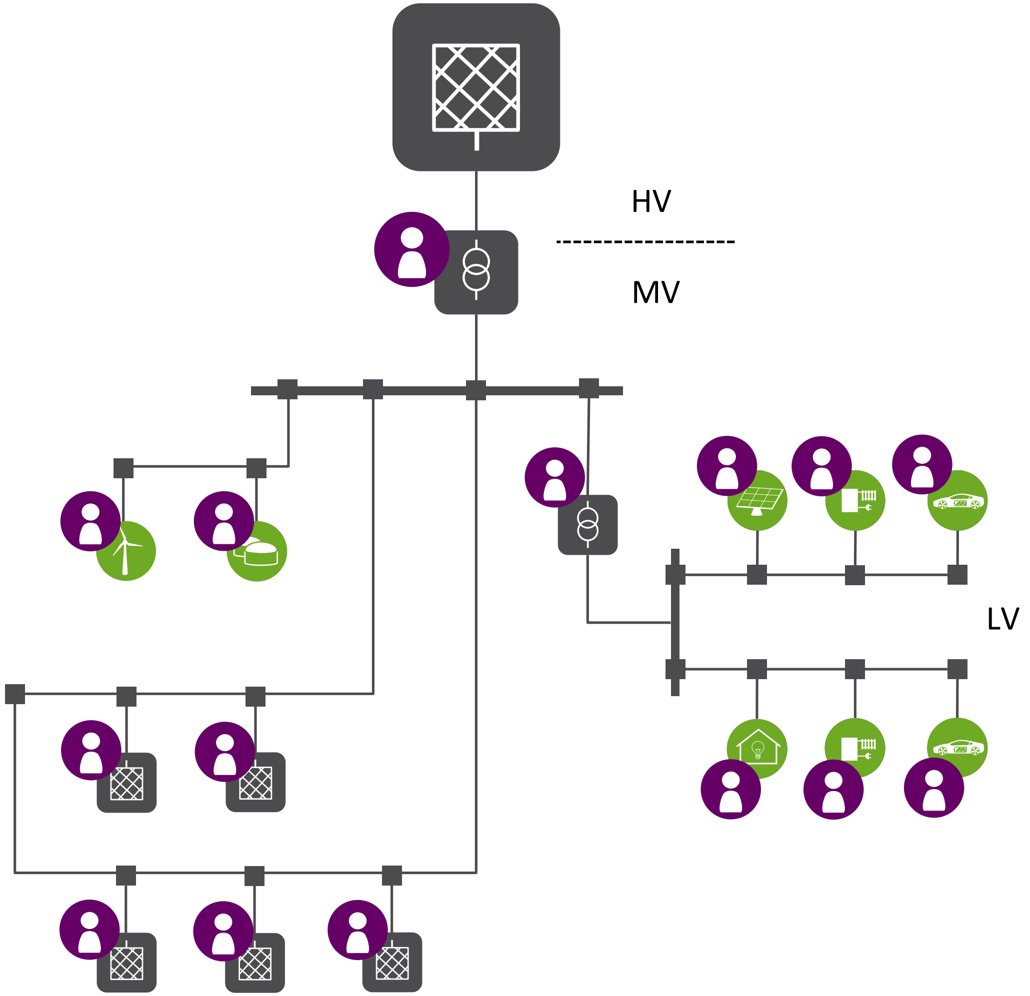
→**Inefficiency, ineffectiveness, instability**

→**DSO/TSO-cooperation has to be strengthened**

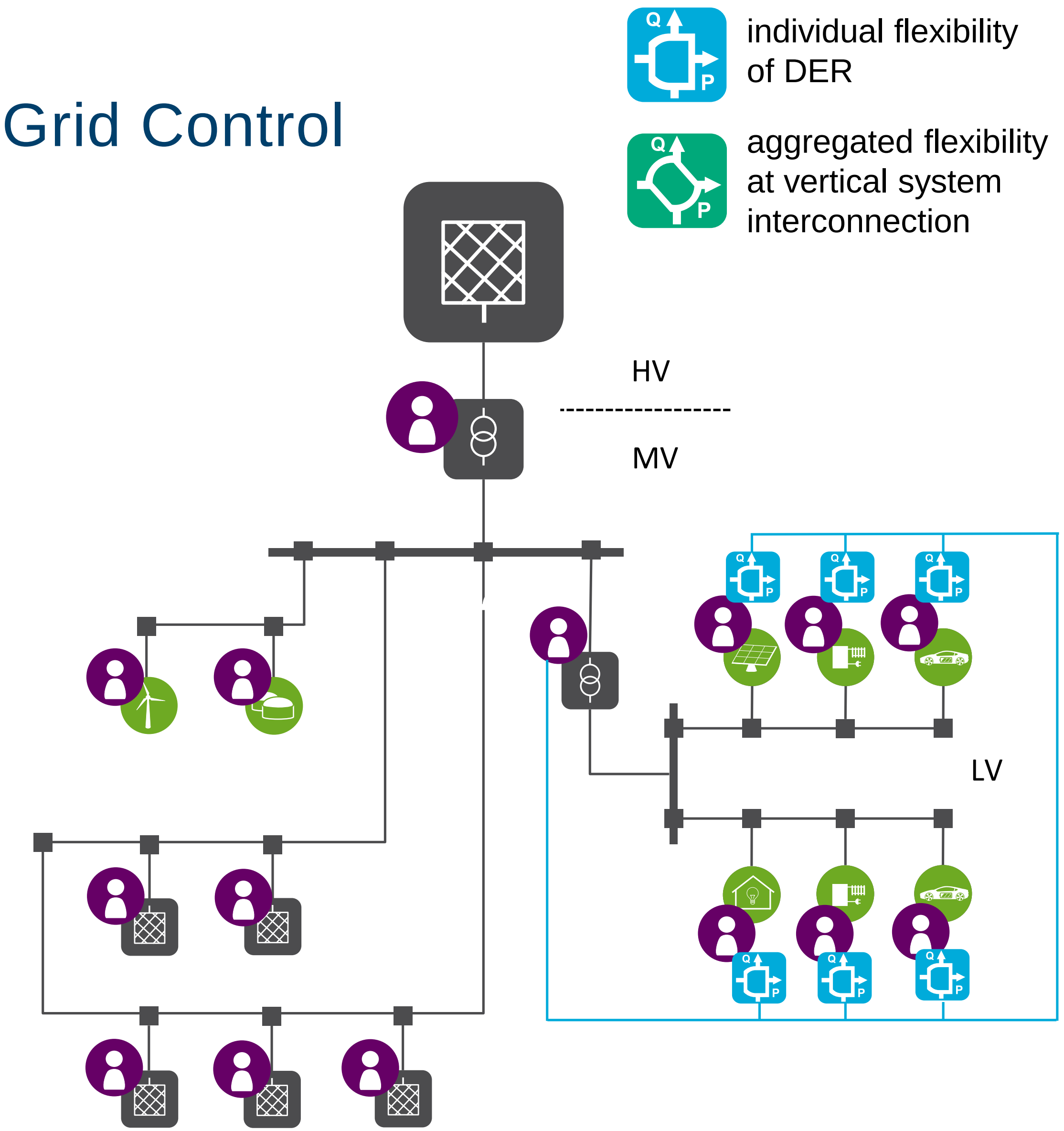
→**Need for multi-voltage-level grid control strategies**



Hierarchical Multi-Voltage-Level Grid Control



Hierarchical Multi-Voltage-Level Grid Control



DER flexibility

Determination of DER flexibility

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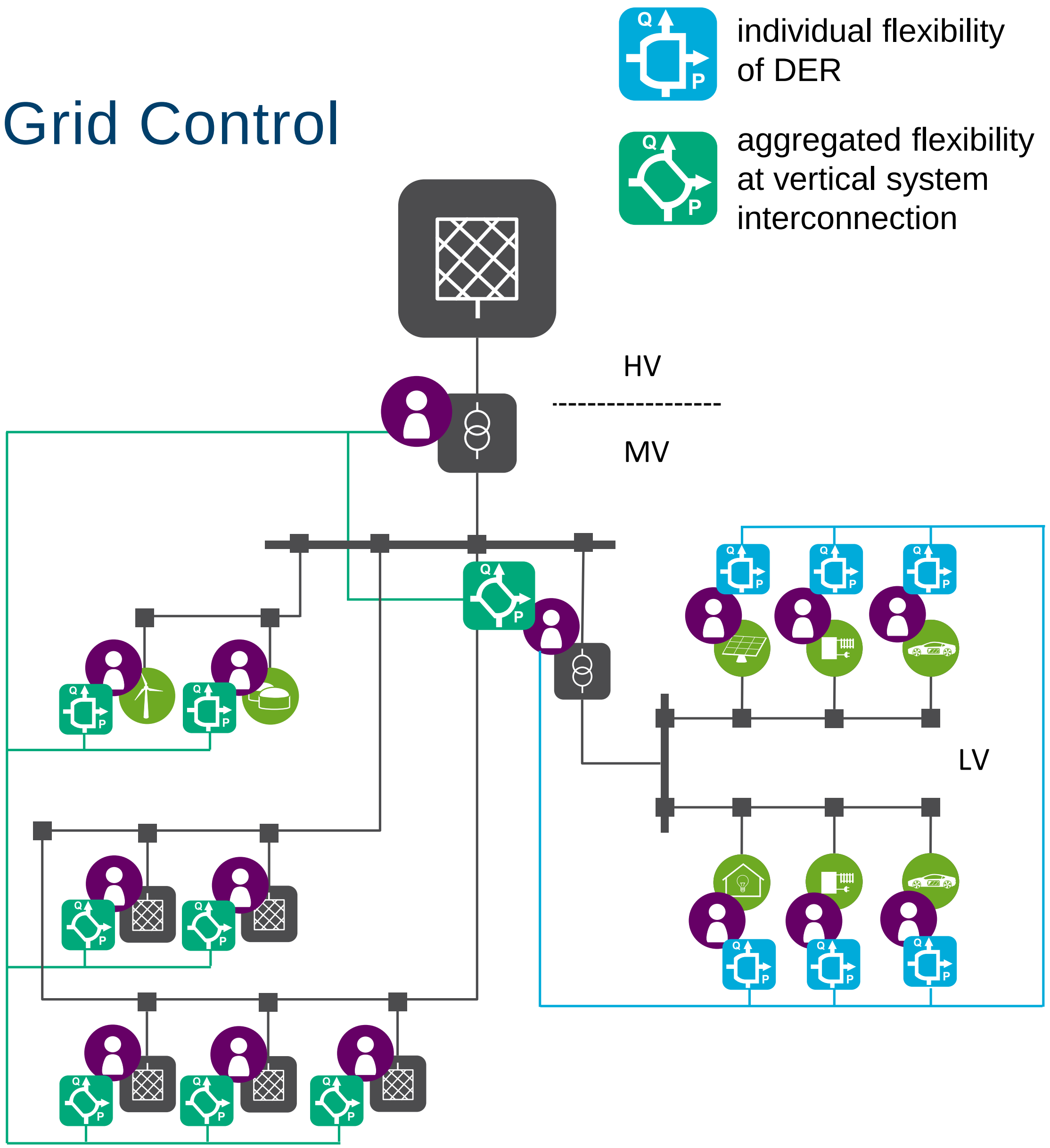
Hierarchical Multi-Voltage-Level Grid Control

subgrid flexibility

Determination of aggregated flexibility

DER flexibility

Determination of DER flexibility



Hierarchical Multi-Voltage-Level Grid Control

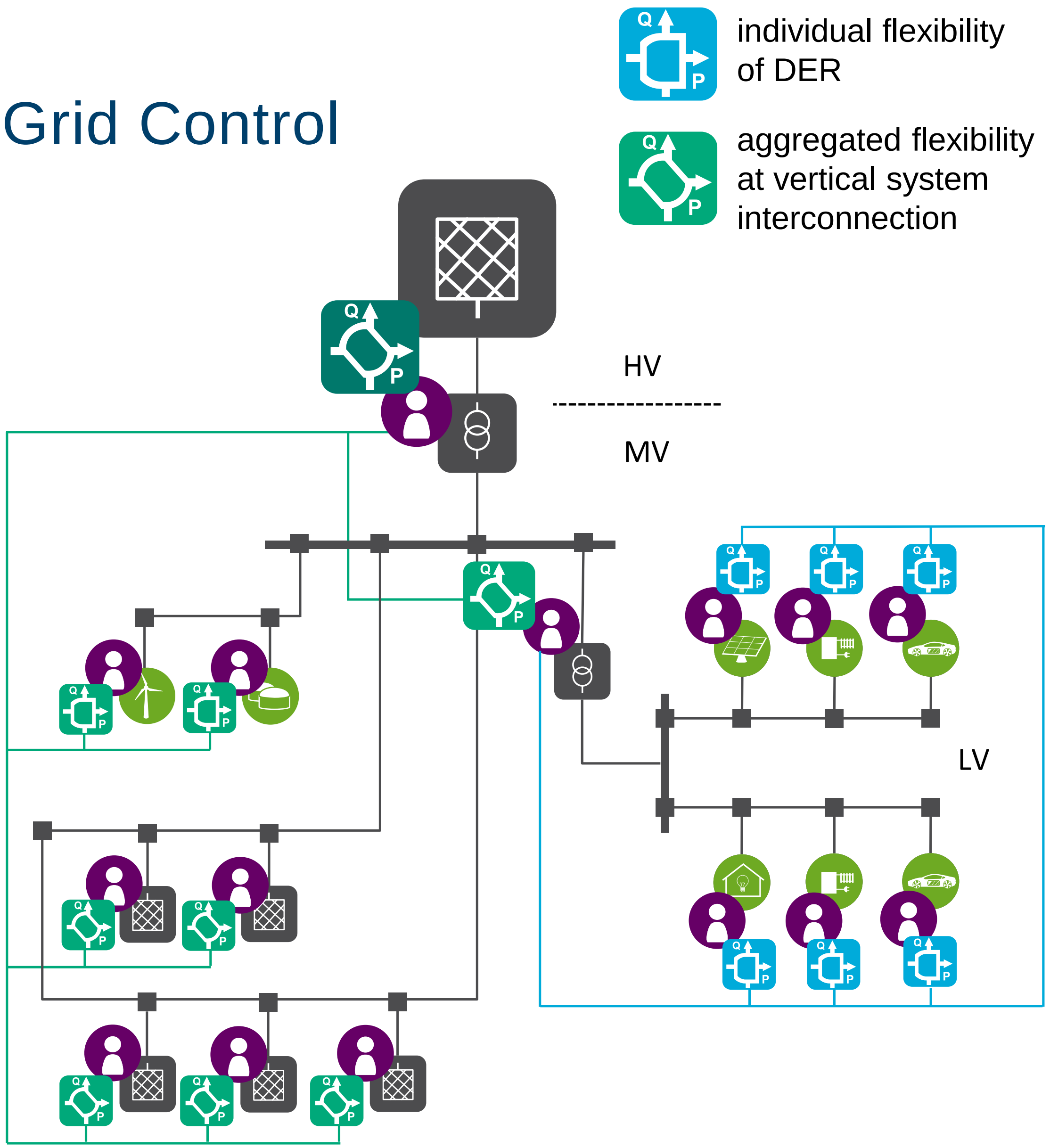
Operational management and optimization

subgrid flexibility ↑

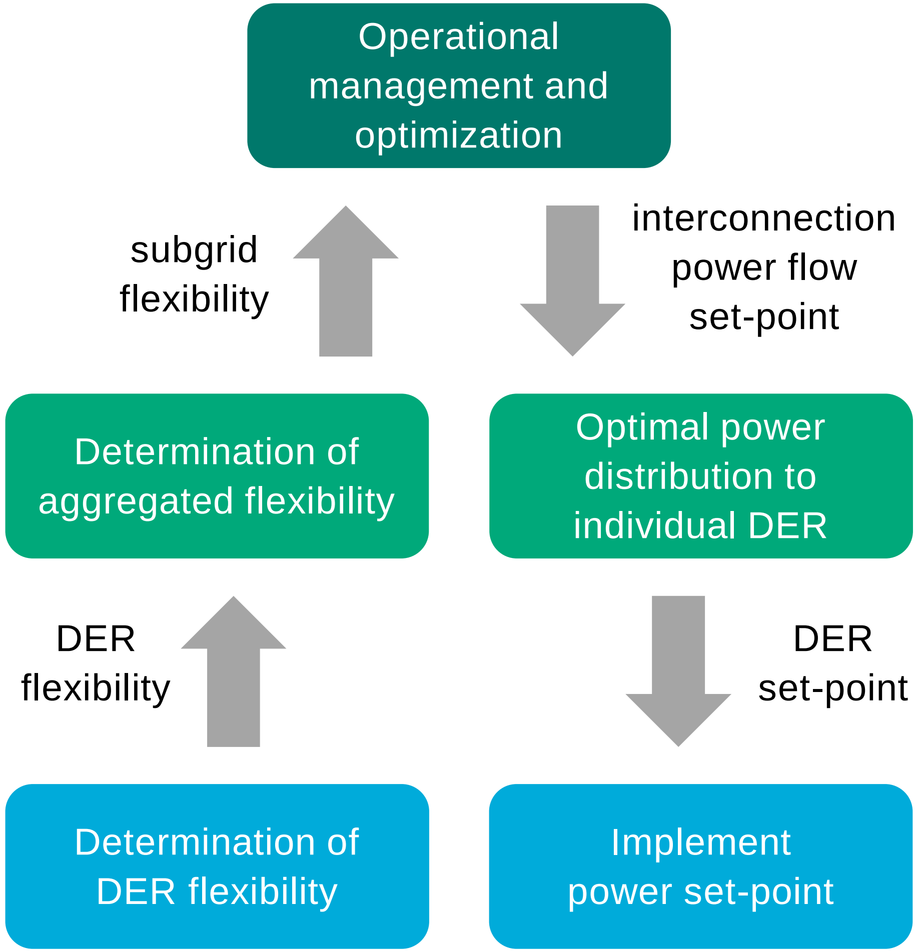
Determination of aggregated flexibility

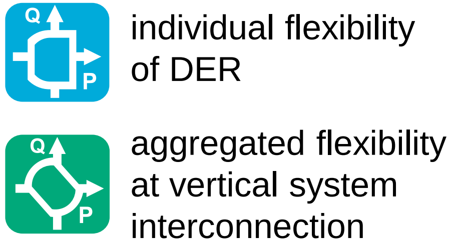
DER flexibility ↑

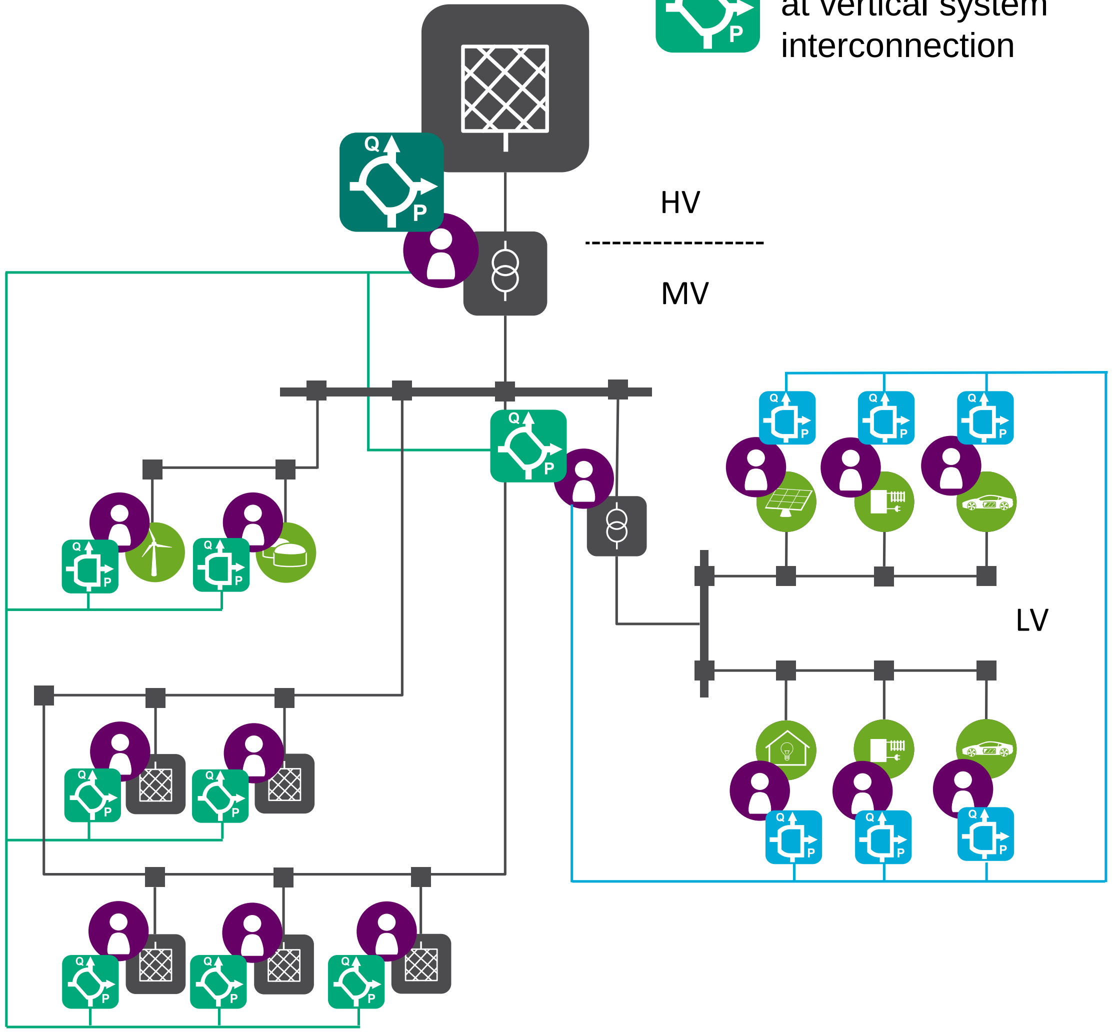
Determination of DER flexibility



Hierarchical Multi-Voltage-Level Grid Control







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Hierarchical Multi-Voltage-Level Grid Control

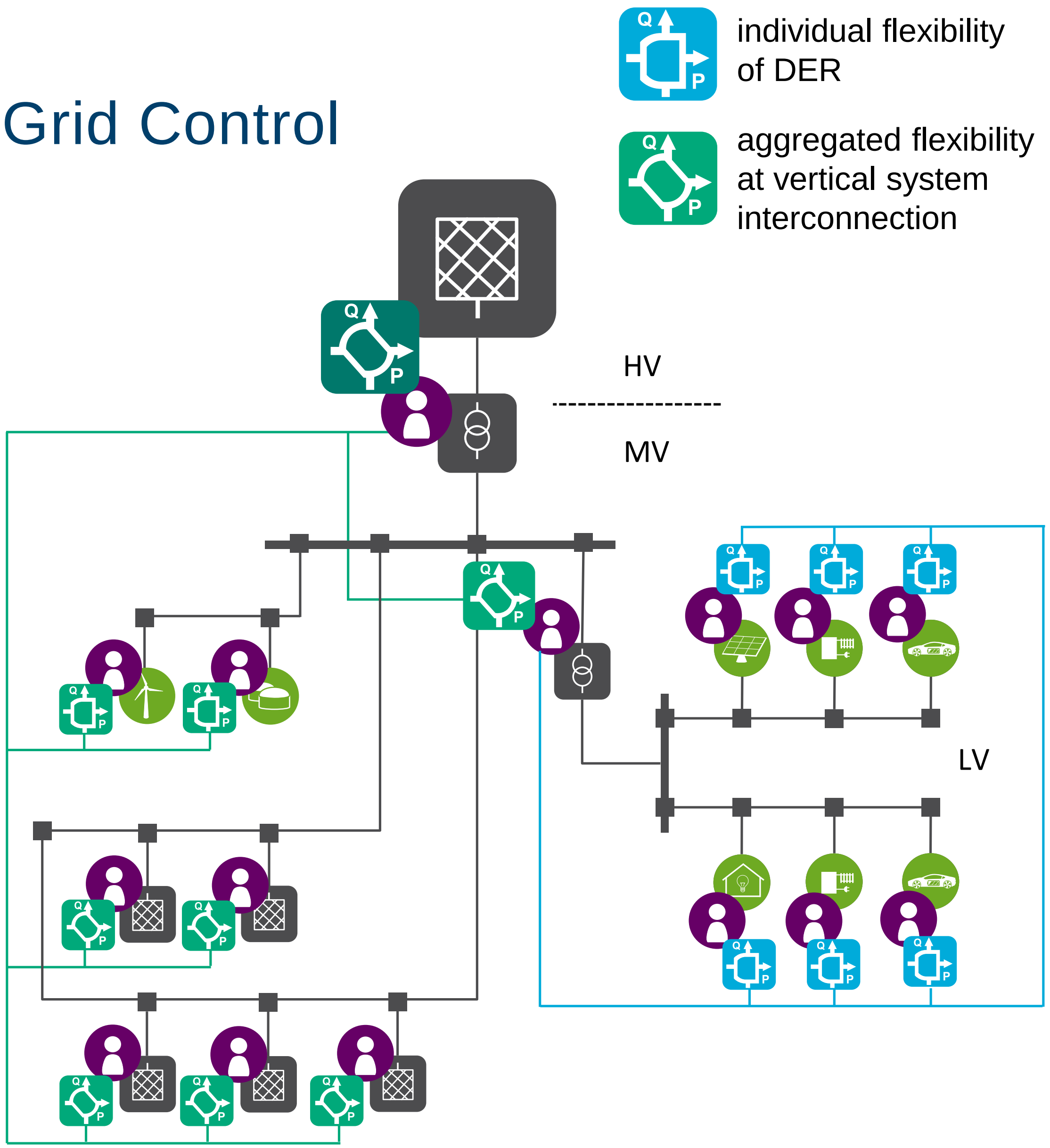
Operational management and optimization

subgrid flexibility ↑ | ↓ interconnection power flow set-point

Determination of aggregated flexibility | Optimal power distribution to individual DER

DER flexibility ↑ | ↓ DER set-point

Determination of DER flexibility | Implement set-point



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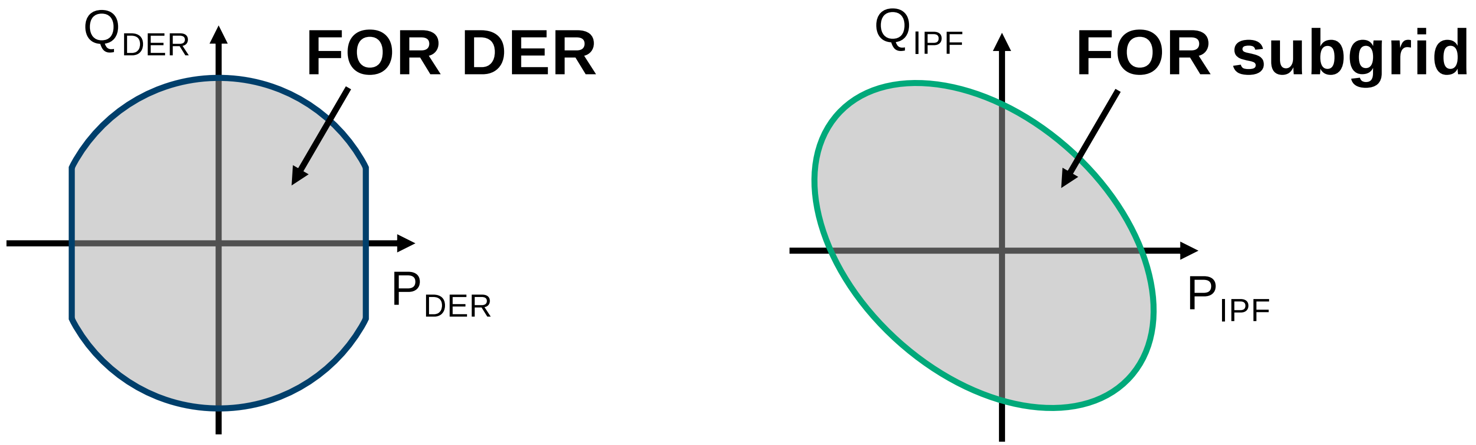
Flexibility Modelling – Flexible Operation Region (FOR)

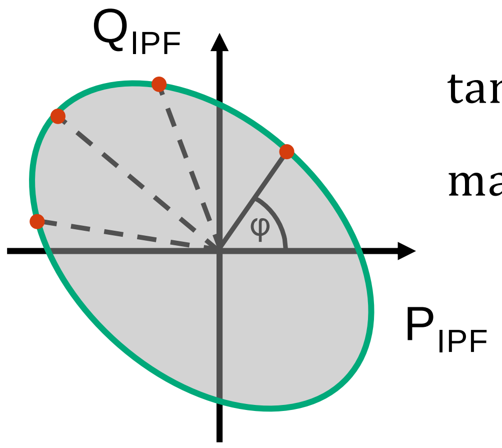
- **Flexible Operation Region (FOR):** Set of feasible PQ-combinations



- **Feasible:** No constraint violations
  - **DER constraints:** e.g., active power limits, apparent power limits, technical limits of inverter
  - **Grid constraints:** voltage limits, maximum line currents

Flexibility Aggregation Methods and Contribution

- **Random sampling** and **optimization based** methods
- **Optimization based**
  - Series of **OPF problems**
  - Requires **explicit grid models**



$$\tan\varphi = \frac{\beta}{\alpha}$$

$$\max(\alpha P_{IPF} + \beta Q_{IPF})$$

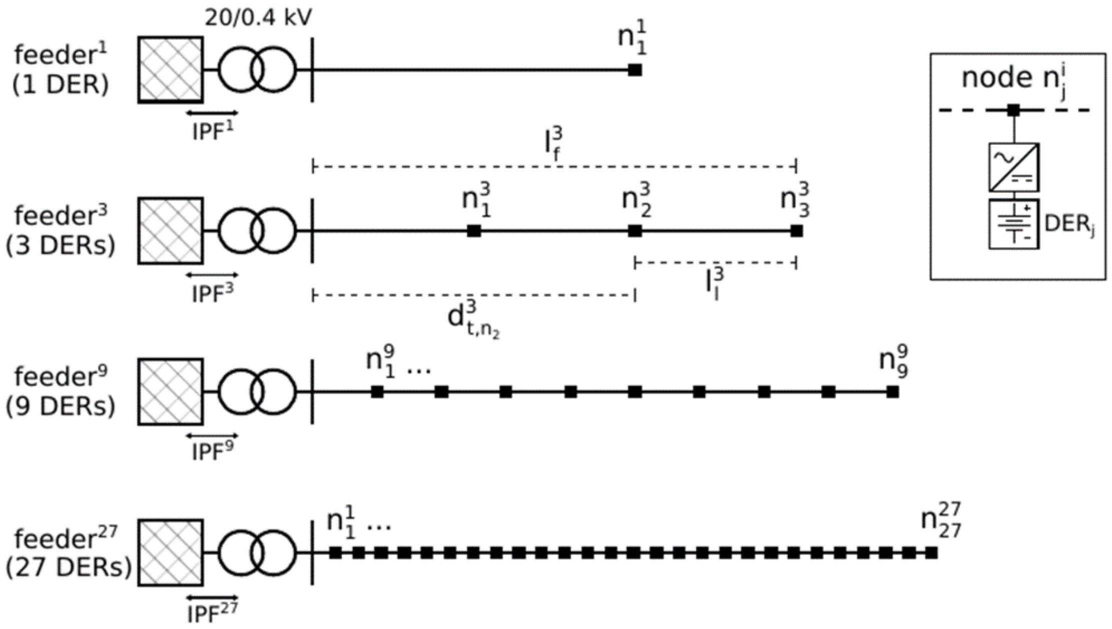
- **Random sampling based**
  - Power set-values are typically drawn from **uniform distributions**
  - With larger grids, the FOR is not covered well → **convolution problem**
- **Contribution of presented paper**
  - **Experiment setup** to **show** and **analyze** convolution problem

Experiment Setup

- Consider **effect** of **grid size** (number of nodes) on sample as **isolated** as possible
- Series of **synthetic feeders** with **increasing number** of nodes
- **Total installed power** and **average transformer-node distance equal** for all feeders

$$l_l^i = \overline{d_{t,n}^i} \cdot \frac{2}{N^i + 1}$$

- Installed power **distributed equally** among DERs
- All DERs inverter connected **battery storages**



Sampling

- For **each synthetic feeder** sample with **sample size 2500**
- **Sampling procedure for each sample element:**

1. **Draw real** and **reactive power** set-value for each DER (battery storage) from **uniform distributions**:

$$\mathcal{U}[P_{min,DER}, P_{max,DER}] \qquad \mathcal{U}[Q_{min,DER}, Q_{max,DER}]$$

2. **Calculate power flow** with pandapower library
3. **Classify** result with regard to its **feasibility**

- Plot sample in the domain of **active** and **reactive** interconnection power flows $\mathbf{P_{IPF}}$ and $\mathbf{Q_{IPF}}$

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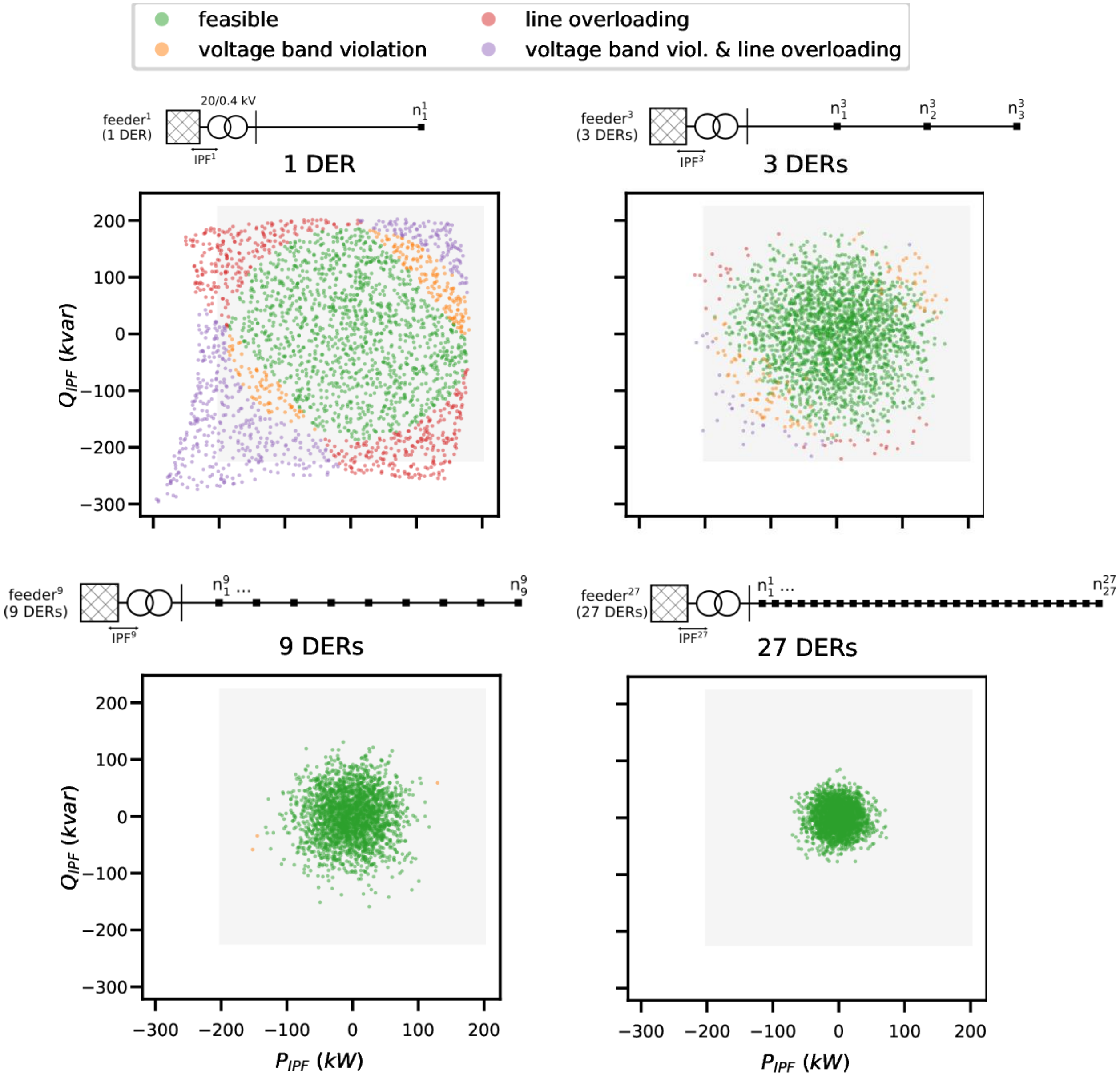
Experiment Results

- Classification with regard to **grid constraints**
  - voltage band violation
  - line overloading
- **Collapsing** point cloud with increasing number of nodes
  - → **folding problem**
- **Border** between feasible and infeasible becomes **less distinct**



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Convolution Problem

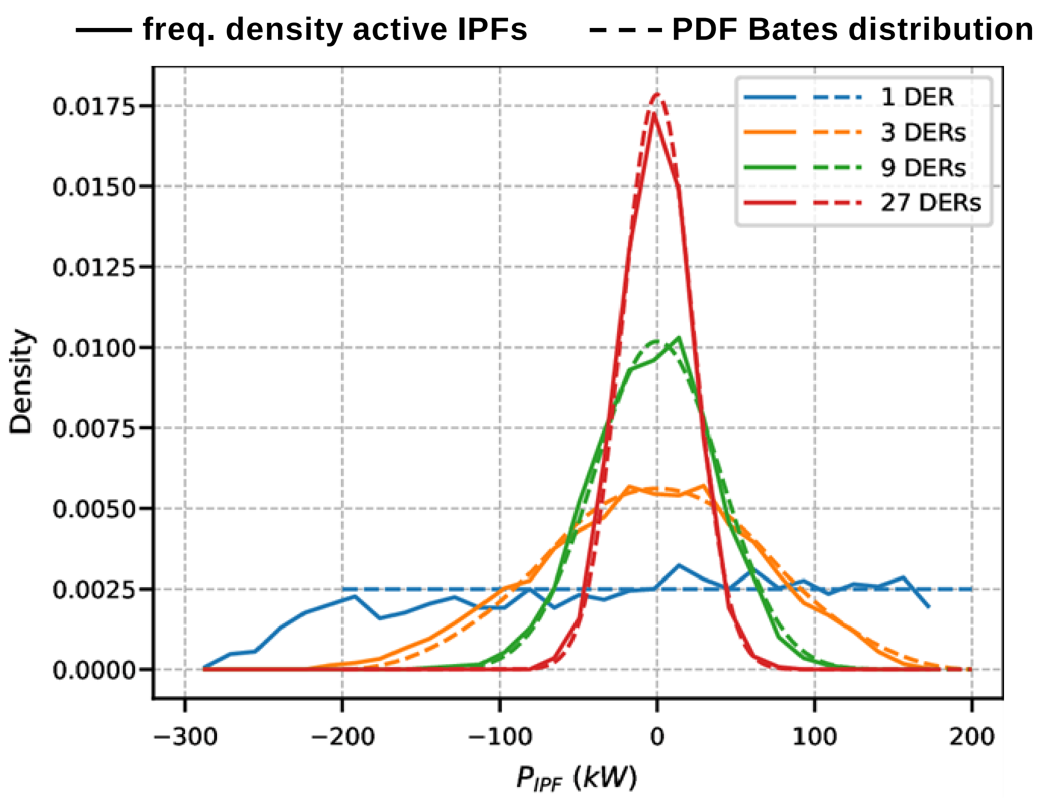
– Distribution of the **sum** of **independent random variables** is the **convolution** of their **individual distributions**

$$\chi_{P,DER_j} = \mathcal{U}\left[\frac{P_{min,total}}{N}, \frac{P_{max,total}}{N}\right] = \frac{1}{N}\mathcal{U}[P_{min,total}, P_{max,total}] \quad (1)$$

$$P_{IPF} = \sum_{j=1}^{N} P_{DER_j} + P_{loss} \quad (2)$$

$$\chi_{P,IPF} \sim \sum_{j=1}^{N} \frac{1}{N}\mathcal{U}[P_{min,total}, P_{max,total}] = \frac{1}{N}\sum_{j=1}^{N}\mathcal{U}[P_{min,total}, P_{max,total}] \quad (3)$$

Bates distribution

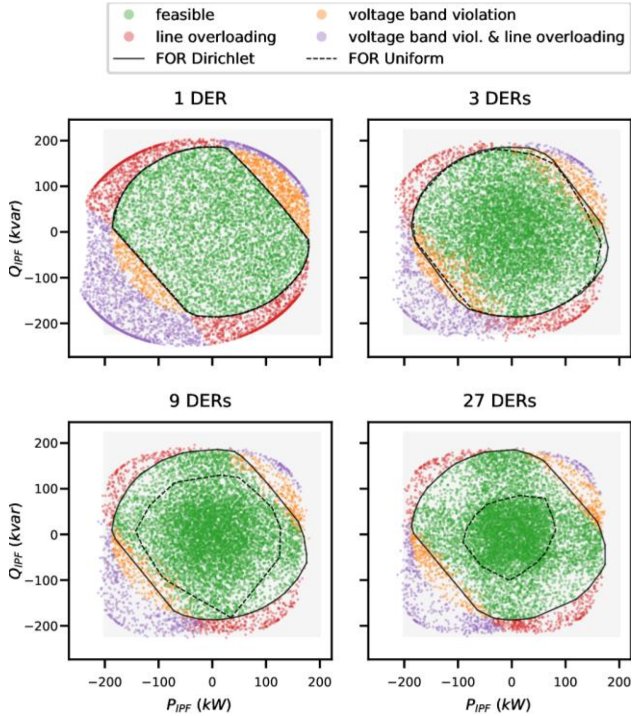


Conclusion

- We **motivated** the use of **flexibility aggregation methods** in the context of **hierarchical multi-voltage-level grid control**
- We **recapped** different **types** of **flexibility aggregation methods**
- We **presented** an **experiment setup** to point out the **convolution problem** when sampling from **independent uniform distributions**
- We **showed** and **discussed** the convolution problem by means of our **experiment results**
- Finally, we **derived** that the **distribution** of the **active IPFs** corresponds approximately to a **Bates distribution**

Future Work

- This work is the **starting point** for the development of **improved** flexibility aggregation methods
  - good coverage of **FOR (**mitigate the convolution problem)
  - **compatible** with **black-box** grid models



- **Two approaches**
  - Make **OPF-based approach** compatible with **black-box** grid models by using **heuristics** for solving OPFs (**CMA-ES** and **REvol)**
  - **Two-stage** random sampling approach from **Dirichlet distribution**
  - **Preliminary results** are **promising**

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