Karlsruhe Institute of Technology

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

Institute for Automation and Applied Informatics (IAI)

Privacy-Preserving Flexibility Provisioning Approaches for Enhanced TSO-DSO Interaction

Xinliang Dai, Burak Dindar, Yanlin Jiang, Frederik Zahn, Dr. Hüseyin K. Çakmak, Prof. Dr. Veit Hagenmeyer

Motivation

- As power systems continue to evolve, efficiently utilizing **flexibility** from the **distribution system (DS)** is becoming increasingly important for **effective network management.**
- Achieving this, however, depends on seamless **interoperability** between key stakeholders, such as **Transmission System Operators (TSOs) and Distribution System Operators (DSOs).**
- However, **data privacy concerns –** such as **potential exposure of network topology and customer load profiles –** among stakeholders present **significant challenges** for **utilizing this flexibility effectively.**

Flexibility Aggregation Approach

Hierarchical graph abstraction of ITD systems

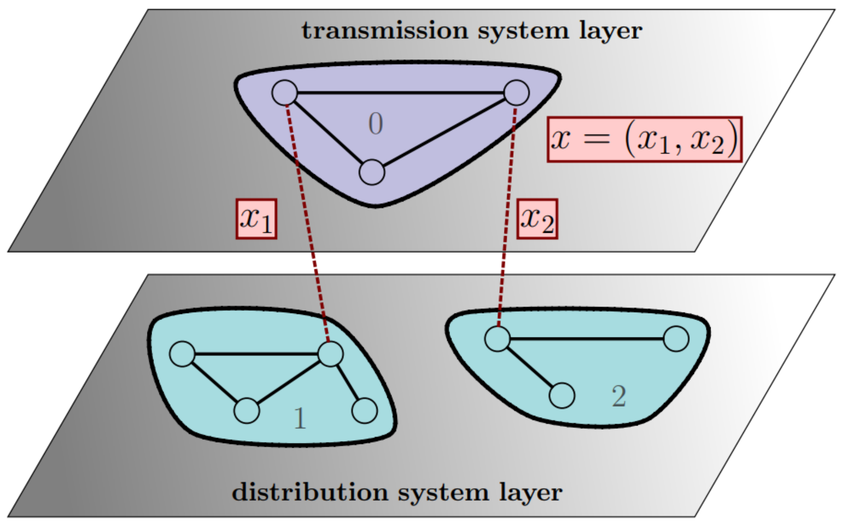


Figure 1: Hierarchical graph of an ITD system

- Hierarchical optimization

$$\min_{x,y} \quad f_0(x, y_0) + \sum_{\ell \in \mathcal{D}} f_\ell(x_\ell, y_\ell)$$
$$\text{s.t.} \quad c_0(x, y_0) = 0,\ y_0 \in \mathcal{Y}_0$$
$$c_\ell(x_\ell, y_\ell) = 0,\ x_\ell \in \mathcal{X}_\ell,\ y_\ell \in \mathcal{Y}_\ell, \qquad \forall \ell \in \mathcal{D}$$

- Optimization without considering DS model explicitly

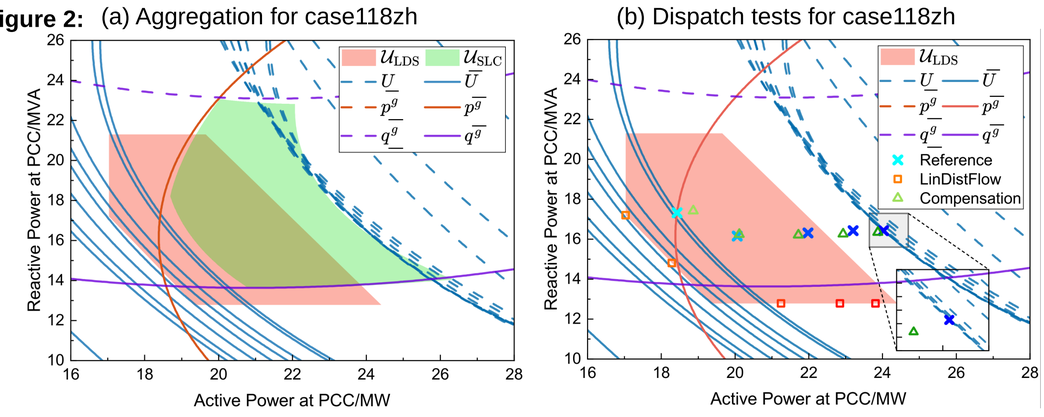
$$\min_{x,y} \quad f_0(x, y_0) + \sum_{\ell \in \mathcal{D}} \hat{f}_\ell(x_\ell)$$
$$\text{s.t.} \quad c_0(x, y_0) = 0,\ y_0 \in \mathcal{Y}_0$$
$$x_\ell \in \mathcal{X}_\ell^{\text{imp}}, \qquad \forall \ell \in \mathcal{D}$$

- Approximation of the implicit feasible set of the DS model

$$\mathcal{X}_\ell^{\text{imp}} = \{x_\ell \in \mathcal{X}_\ell \mid g_\ell(x_\ell, y_\ell) = 0,\ y_\ell \in \mathcal{Y}_\ell\}$$

Results

Figure 2: (a) Aggregation for case118zh (b) Dispatch tests for case118zh



Machine Learning Approach

Representation of DS using ML models

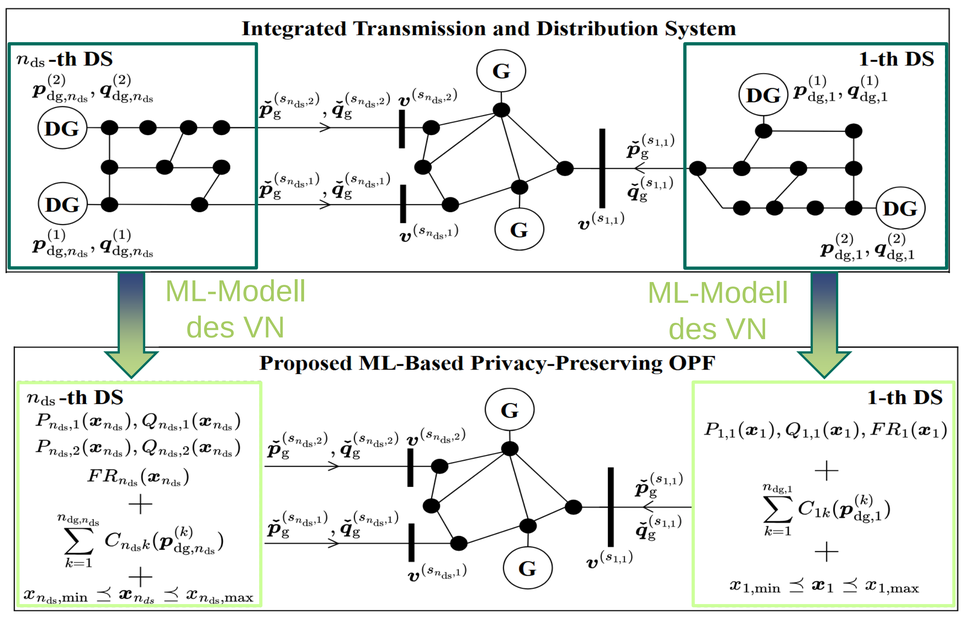


Figure 3: Schematic representation of the proposed ML-based method

- With ML models the TSO can incorporate DGs located within the DS into dispatch decision.

Representation of DS feasible space

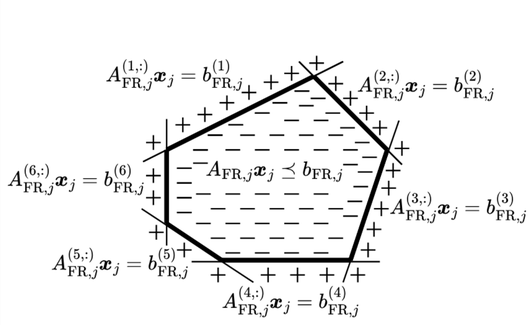


Figure 4: Schematic representation of the polytope

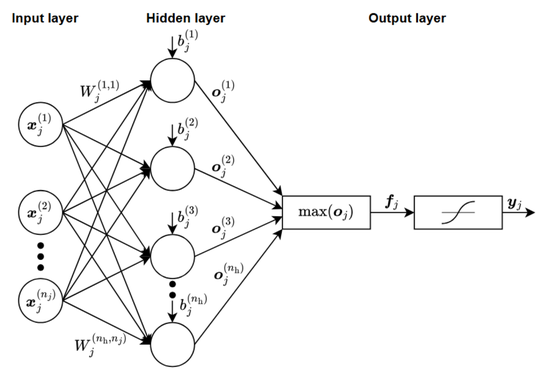


Figure 5: The architecture of the novel tailored NN

- We represent the DS feasible region as a convex polytope by developing a novel NN architecture that defines this polytope using a set of linear inequalities with high computational efficiency.

Results

Table 1 Accuracy, Recall and Specificity Metrics of the NN Models

Model	Accuracy	Recall	Specificity
$FR_1(\boldsymbol{x}_1)$	99.90%	99.89%	100.00%
$FR_2(\boldsymbol{x}_2)$ - $FR_3(\boldsymbol{x}_3)$	94.79%	93.03%	97.01%

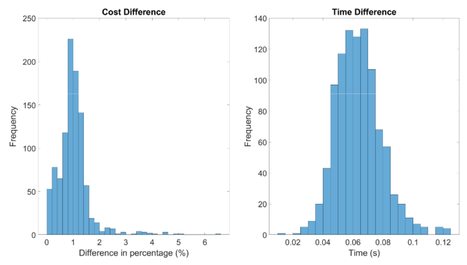


Figure 6: The histogram of the total cost and computational time differences taking AC-OPF as reference.

Conclusion

- Both methods enable **fast flexibility calculation** as **non-iterative distributed** approaches.
- Both of these approaches enable **the effective use of DS flexibility in network management** with subject to **physical constraints.**
- Both methods **preserve data privacy**, ultimately fostering **greater interoperability** among stakeholders.