Karlsruhe Institute of Technology

HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES
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Distributed Coordination Framework for Integrated T&D Systems

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Motivation

The rapid integration of distributed energy resources (DERs) has significantly increased the complexity of interactions between transmission and distribution grids.

For German TSOs, enhancing cooperation is required, both horizontally among TSOs and vertically with numerous DSOs.

Centralized coordination faces resistance from system operators and potential conflicts with regulations, due to challenges in maintaining data privacy and decision-making independence.

Methodology

Real-time Distributed Framework

Distribution Level: DSOs calculate and provide the aggregated flexibility of controllable devices to TSOs using power-energy envelopes.

Transmission level: economic dispatch across TSOs is optimized using a receding horizon method, incorporating the aggregated flexibility from all adjacent distribution systems.

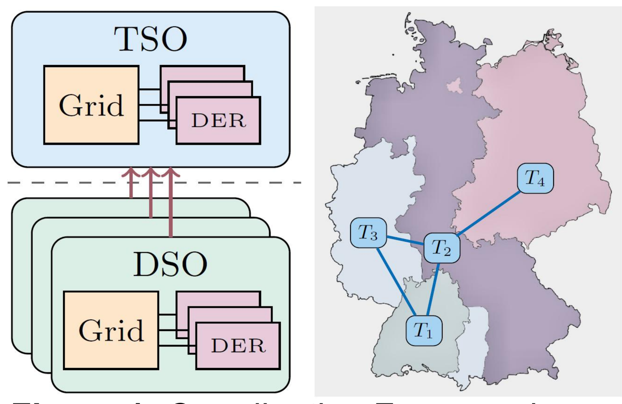


Figure 1: Coordination Framework

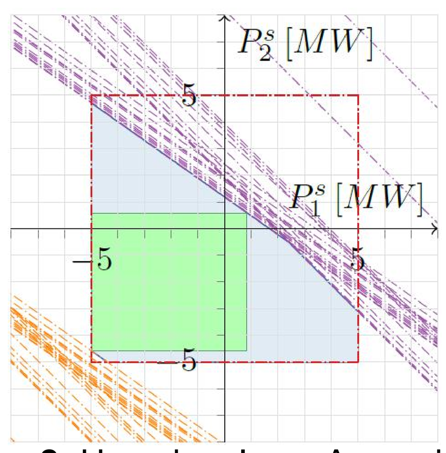


Figure 2: Hyperbox Inner Approximation for Enhanced Flexibility in Distribution

Distributed Optimal Dispatch Problem with Receding Horizon

$$\min \sum_{k\in\mathcal{K}}\sum_{\ell\in\mathcal{R}} f_{k,\ell}(x_{k,\ell}) \quad \text{Decoupled Objective}$$

$$\text{s.t. } \forall k\in\mathcal{K},\ \sum_{\ell\in\mathcal{R}} \Gamma_{k,\ell}x_{k,\ell}=0 \ \mid \lambda_k \quad \text{Spatial Couplings}$$

$$\text{s.t. } \forall \ell\in\mathcal{R},\ \sum_{k\in\mathcal{K}} \Lambda_{k,\ell}x_{k,\ell}=0 \ \mid \kappa_\ell \quad \text{Temporal Couplings}$$

$$\text{s.t. } \begin{cases} \forall k\in\mathcal{K},\ \forall \ell\in\mathcal{R} \\ h_{k,\ell}(x_{k,\ell})\le 0 \qquad \mid \nu_{k,\ell} \end{cases} \quad \text{Decoupled Constraints}$$

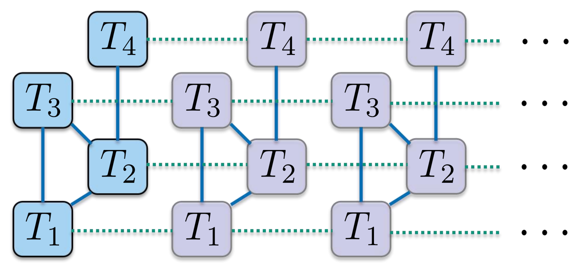


Figure 3: Optimal Dispatch Problems with Receding Horizon

Optimal dispatch problems are decoupled across both different *system operators* and *periods* (spatial and temporal decomposition), with each subproblem representing an individual single-period AC OPF of a single transmission system.

Distributed Optimization Algorithm

Utilizing local measurements, augmented Lagrangian based Alternating Direction Inexact Newton method (ALADIN) is tailored to efficiently solve the distributed optimal dispatch problem. This approach ensures the preservation of data privacy and supports independent decision-making.

Implementation

Geographically Distributed Co-Simulation Framework

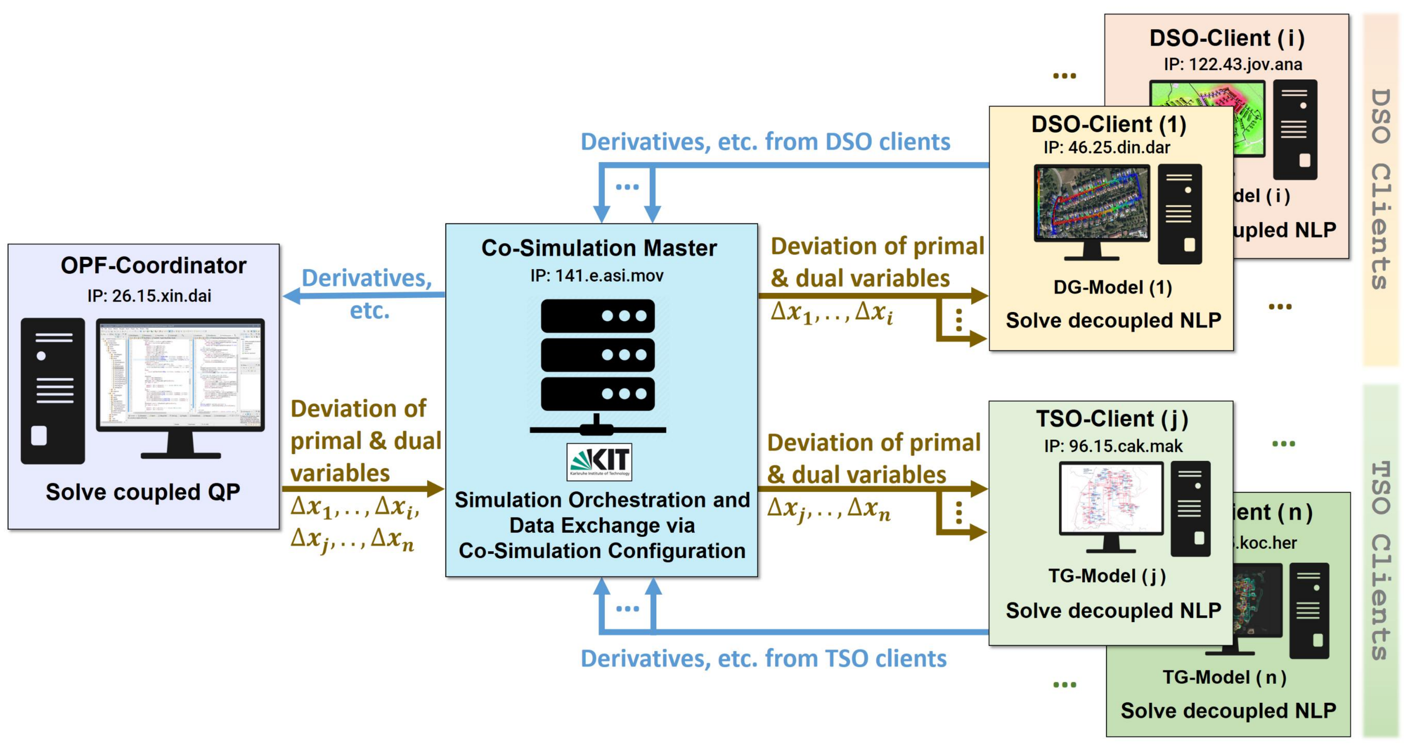


Figure 4: ***E***lectrical ***G***rid ***A***nalysis, ***Si***mulation, ***M***odeling, ***O***ptimization and ***V***isualization (eASiMOV)

Parallel and Cloud Computing

Cooperation with industry partner TRANSNET BW, one of four TSOs in Germany.

Results

Case Study

Transmission system encompassed four 118-bus systems from PGLib, interconnected with ten 33-bus systems representing the distribution systems each, totaling 1792 buses.

The optimal dispatch problem covers a 24-hour period with 96 time-intervals of 15 minutes each, resulting in transmission-level optimization problems consisting of 187,776 state variables across 384 subproblems.

The simulation operates over one day, and all 96 dispatch problems in the daily operation exhibit fast convergence within 500 seconds and a few iterations. Simulations using real operational data, despite significant prediction mismatches, demonstrate that our approach is practical for real-world applications.

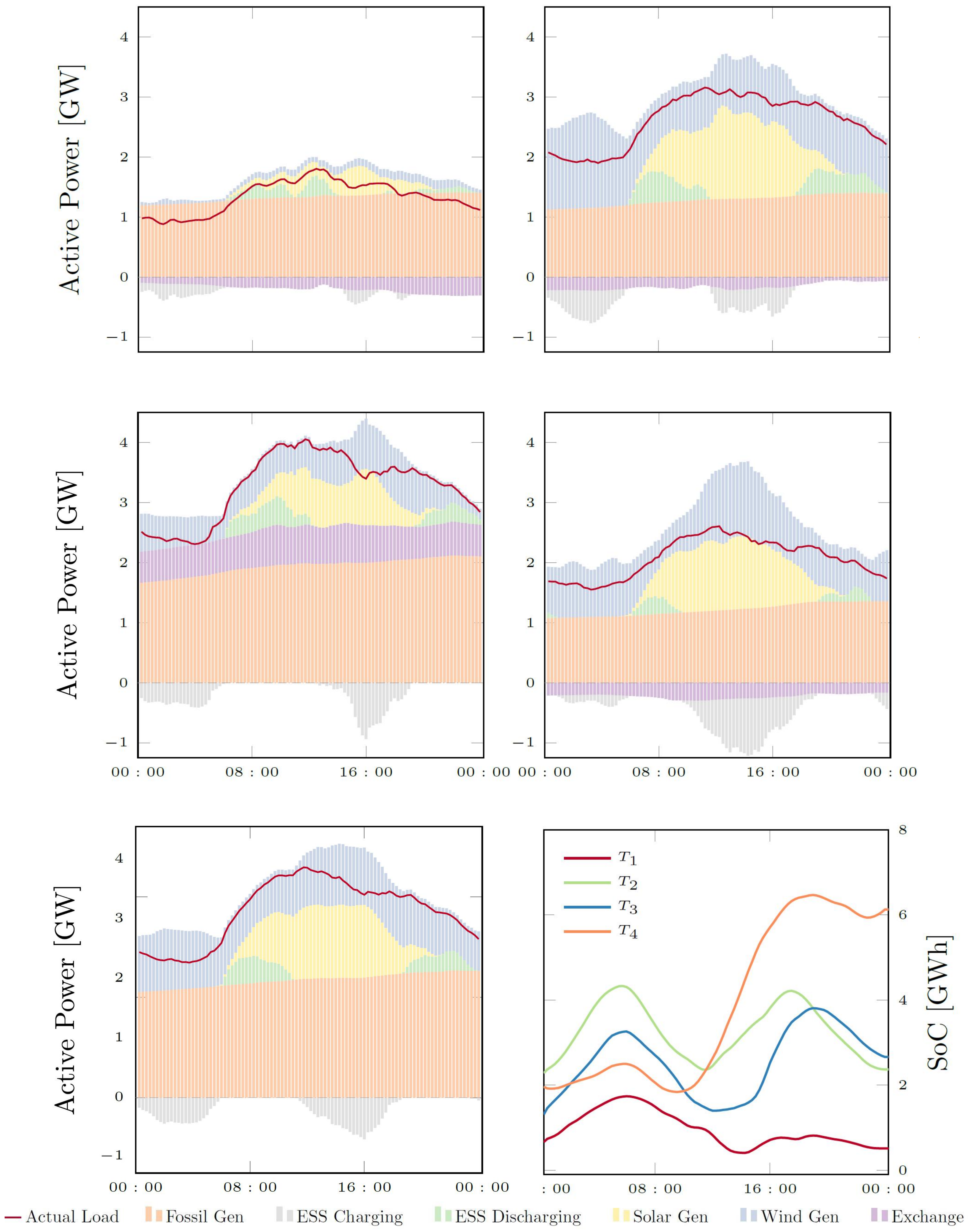
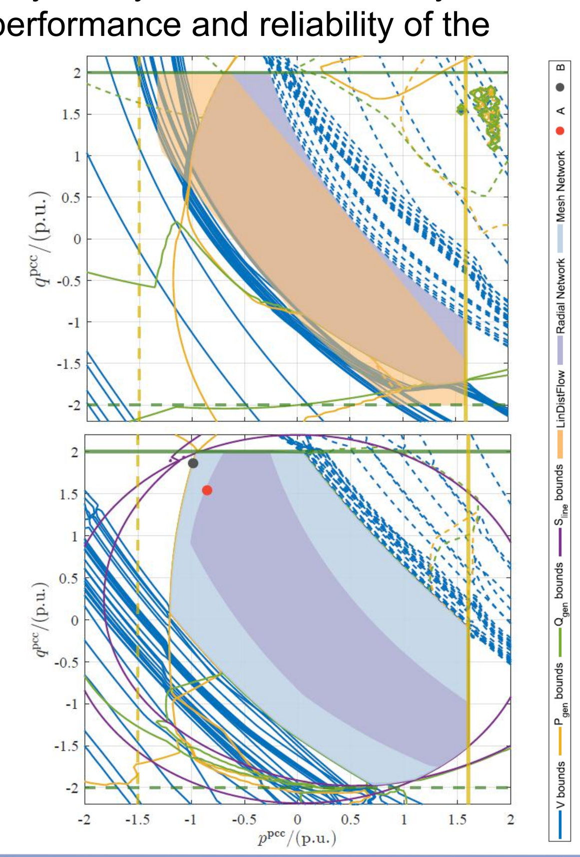


Figure 5: Optimal dispatch with receding horizon by distributed approach, using measurement data from the ENTSO-E Platform on July 24, 2023, a day marked by heavy rainfall in Germany and notable for significant prediction mismatch, for analysis the performance and reliability of the proposed approach under adverse weather conditions.

Discussion on Flexibility Aggregation

By visualizing the flexibility of distribution systems at the point of common coupling, our findings underscore the importance of accurate modeling and the strategic transition of distribution network configurations from radial to mesh topology to support the integration of distributed energy resources (DERs), thus contributing to power systems' reliability, efficiency, and sustainability.



1. **Xinliang Dai**, Yi Guo, Yuning Jiang, Colin N. Jones, Gabriela Hug, and Veit Hagenmeyer. *Real-Time Coordination of Integrated Transmission and Distribution Systems: Flexibility Modeling and Distributed NMPC Scheduling.* PSCC2024, accepted. DOI: 10.48550/arXiv.2402.00508
2. **Xinliang Dai**, Alexander Kocher, Jovana Kovačević, Burak Dindar, Yuning Jiang, Colin N. Jones, Hüseyin Çakmak, Veit Hagenmeyer. *Ensuring Data Privacy in AC Optimal Power Flow with a Distributed Co-Simulation Framework.* PSCC2024 accepted. DOI: 10.48550/arXiv.2402.01001

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