A MODEL-BASED COMPARATIVE STUDY OF PEER-TO-PEER MARKET DESIGNS

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Overview

With the rise of distributed energy resources (DERs), peer-to-peer (P2P) trading has emerged as a complement to traditional power supply models, offering potential benefits for both residential consumers and for alleviating grid congestion [1]. This study presents a model-based comparative analysis of three P2P market designs: auction-based pricing (ABP), supply-demand ratio pricing (SDR), and mid-market rate pricing (MMR). We consider these P2P market designs under both a real-time pricing (RTP) and a fixed retail price setting. The analysis examines the impact of these market designs on: DER investments, electricity bills, system-wide efficiency, and impact on the local grid. Our results show that P2P trading significantly reduces consumer electricity costs, although savings are less pronounced under RTP contracts due to narrower price gaps between retail offtake and injection prices. Among the evaluated mechanisms, ABP yields the lowest total consumer bills but can exacerbate local grid issues due to concentrated power injections at specific nodes. In contrast, the MMR and SDR mechanisms mitigate congestion by distributing offtake and injection more evenly across peak hours. Notably, we also show that P2P trading can achieve consumer cost savings comparable to RTP contracts while contributing to system-level efficiency, all without exposing consumers to granular price signals, making it a viable alternative in markets where RTP adoption faces challenges.

Methods

In a case study, we consider a P2P market with 20 residential consumers and examine eight cases by combining three P2P market mechanisms and a conventional non-P2P trading setting, with both an RTP and a flat retail rate contract. Each residential consumer in the P2P market act as an independent decision-maker aiming to minimize their electricity bill by optimizing their investment in DERs and operational decisions over a one-year horizon. The trading among all P2P market participants is modelled as a non-cooperative game.

To evaluate the impact of various P2P market mechanisms on the grid infrastructure, an ex-post power flow analysis is conducted using the P2P market simulation outcomes. This analysis is performed on eight independent representative feeders from a real European low-voltage urban distribution network [2], using the non-convex, non-linear AC power flow formulation. As we focus on a local market within a single feeder to evaluate the maximum potential benefits of P2P trading, we assume twenty households in this feeder are enabled for demand response and participation in the local P2P market, while the remaining households have non-controllable loads. The 20 participating consumers are randomly distributed along the feeder and connected to the grid with either single-phase or three-phase connections.

To guarantee the robustness of our results, we conduct a comprehensive sensitivity analysis in two stages. First, we start by performing 50 market simulations for the eight cases, with each simulation using 20 distinct consumer profiles. The market outcomes from these simulations are then applied to five different random allocations of consumers across the eight representative feeders. Consequently, for each market setup, we perform 40 power flow analyses to derive a more generalized conclusion on the impact of different P2P market mechanisms on local grids.

Results

We compare the different P2P market designs by particularly focusing on the consumers' electricity bills, DER investments, local P2P market prices, self-consumption, the system cost and the impact on the local grid.

Our findings show that P2P markets, regardless of the specific design, can effectively reduce consumer electricity bills. This reduction, however, is notably smaller under an RTP contract due to narrower price differences between retail offtake and injection prices. Nevertheless, P2P markets present a viable alternative to RTP contracts by delivering comparable cost savings for consumers while also contributing to broader system-level benefits. Among the evaluated designs, the ABP mechanism yields the lowest total consumer bills, a high self-consumption index, and relatively low system costs, making it particularly attractive for maximizing consumer economic benefits and promoting system-wide efficiency. However, it encourages consumers to concentrate electricity injections at specific nodes, which increases the frequency and severity of local grid issues and making it less suitable for less resilient distribution grids. In contrast, MMR and SDR mechanisms distribute offtake and injection more evenly, reducing peak loads and alleviating grid congestion. These mechanisms are better suited for feeders with limited capacity or weaker grid infrastructures.

Conclusions

This study provides a model-based, quantitative comparison of three P2P market designs, each combined with two types of retail contracts. Unlike prior research, our analysis extends beyond consumer benefits to examine the broader implications of P2P trading on the energy system and local grid performance. By evaluating these mechanisms under both flat retail rates and RTP contracts, we address practical challenges associated with RTP adoption, such as implementation complexity, price unpredictability, and consumer adaptability to granular price signals. The results demonstrate that different P2P market mechanisms yield distinct market outcomes due to their unique pricing structures, which in turn affect DER investment, battery operation, consumer bills, system costs, and the burden on the local grid. P2P trading significantly reduces consumer electricity costs, offering savings comparable to RTP contracts without requiring exposure to granular price signals. This makes it a viable alternative in markets where RTP adoption faces challenges. Among the evaluated mechanisms, ABP is the most efficient in reducing system cost and consumer bills but exacerbates grid issues, while MMR and SDR alleviate grid congestion and deliver modest efficiency gains.

References

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