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Local electricity market designs for peer-to-peer trading: The role of battery flexibility☆

Alexandra Lüth[a,b], Jan Martin Zepter[a,b,*], Pedro Crespo del Granado[a,*], Ruud Egging[a]

[a] Dept. of Industrial Economics and Technology Management (IØT), Norwegian University of Science and Technology, Trondheim, Norway
[b] Workgroup for Infrastructure Policy (WIP), Technical University Berlin, Berlin, Germany

HIGHLIGHTS

- Analysis of end-user benefits in smart grids with peer-to-peer trade and battery storage.
- Proposal of two market designs in the presence of two storage location strategies.
- Implementation of a linear optimisation model for a community in London, UK.
- End-user potential savings of 31% due to peer-to-peer trade and private storage.
- Novel ideas for market design to integrate RES based on P2P trade and battery flexibility.

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ABSTRACT

Deployment of distributed generation technologies, especially solar photovoltaic, have turned regular consumers into active contributors to the local supply of electricity. This development along with the digitalisation of power distribution grids (smart grids) is setting the scene to a new paradigm: peer-to-peer electricity trading. The design of the features and rules on how to sell or buy electricity locally, however, is in its early stages for microgrids or small communities. Market design research focuses predominantly on established electricity markets and not so much on incentivising local trading. This is partially because concepts of local markets carry distinct features: the diversity and characteristics of distributed generation, the specific rules for local electricity prices, and the role of digitalisation tools to facilitate peer-to-peer trade (e.g. Blockchain). As different local or peer-to-peer energy trading schemes have emerged recently, this paper proposes two market designs centred on the role of electricity storage. That is, we focus on the following questions: What is the value of prosumer batteries in P2P trade?; What market features do battery system configurations need?; and What electricity market design will open the economical potential of end-user batteries? To address these questions, we implement an optimisation model to represent the peer-to-peer interactions in the presence of storage for a small community in London, United Kingdom. We investigate the contribution of batteries located at the customer level versus a central battery shared by the community. Results show that the combined features of trade and flexibility from storage produce savings of up to 31% for the end-users. More than half of the savings comes from cooperation and trading in the community, while the rest is due to battery's flexibility in balancing supply-demand operations.

1. Introduction

According to the European Union (EU) Strategy Energy Technology Plan [1], consumers (or energy end-users) are envisioned to be at the centre of the future energy system. A successful effort to actively involve consumers is the ongoing deployment and adoption of photovoltaic (PV) panels. Solar has proven to be a viable technology for the consumer, mainly due to policy incentives and its declining costs. Today, a similar narrative is starting to take place for electrical vehicles, batteries and other storage technologies. Batteries are a long-sought technology to increase the flexibility of supply-demand operations and are potentially a key technology in the EU energy transition [2]. Could batteries be the next technology deployed on a mass scale as is the case for solar PV? A current example of this development is the subsidy

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* Corresponding authors at: Technical University Berlin (J.M. Zepter). Norwegian University of Science and Technology (P. Crespo del Granado).
E-mail addresses: jz@wip.tu-berlin.de (J.M. Zepter), pedro@ntnu.no (P. Crespo del Granado).

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households in Germany receive when adding a battery system to their PV array [3].

As a consequence of the surge of distributed generation options (e.g. solar PV, batteries or small scale wind turbines), the rise of the prosumer[1] has brought new challenges to the established supply-demand dynamics in electricity generation and increased the need for on-site flexibility. For instance, in high-generation periods, the supply from renewable energy sources (RES) often exceeds a single prosumer's demand and their total generation therefore might not be fully exploited. The excess energy might be curtailed or fed back into the main grid. Curtailment, however, will reduce the profitability of the prosumer's generation capacity, which might lead them to invest in lower capacity. Feeding into the grid leads to other challenges such as the distributed generated electricity needing a fair price, and current highly subsidised feed-in tariffs might not be sustainable as the number of prosumers grows.

To address some of these challenges, peer-to-peer (P2P) trade has emerged as a new alternative to foster the deployment of distributed generation technologies. It allows a direct interaction between market participants without considering a third party involvement [4]. P2P is the ability to trade electricity with one another (consumer or prosumer), gain revenue for excess power, use a low-cost settlement system to reduce electricity bills and improve returns on investments in distributed generation. P2P trade opens the possibility to switch energy suppliers on a minute-by-minute basis and buying-selling (prosumers) electricity based on one's own preferences. For instance, a P2P system might incorporate blockchain technologies to keep track of the electricity amount traded and have a transparent automated settlement system.

However, P2P energy trade concepts in microgrids are still at an early stage in the literature as there is no consensus on what business model or market design will help to develop local electricity markets. In this regard, the digitalisation of distributed grids will enable P2P trade and facilitate the establishment of local bidding pools that can eventually be linked to existing electricity markets (day-ahead or intraday electricity markets). This will lead to various market design questions, such as: Which local electricity market designs and P2P mechanisms will provide the *right* framework for an efficient exploitation of the digitalisation of power distribution grids? How will the broader electric power market evolve if additional technological features such as local intermittent RES and battery flexibility are introduced? In this paper, we assume that digitalisation technologies and smart grids are installed and have the capability to carry out P2P trade. We focus on the role of battery storage under different distributed energy system configurations and define market governing rules. In other words, we study the battery storage potentials for end-users in the presence of P2P trade guided by the following research questions:

- What is the value of batteries in P2P trade? What new market features do they bring?
- What electricity market design will open the economic potential of end-user batteries?

To address these questions, we develop a P2P trading model (linear programming based) in order to evaluate the end-user benefits of two distinct market designs and distributed generation system configurations centred on the flexibility of battery storage: decentralised versus centralised storage (see Fig. 1). Specifically, the value of battery storage and associated market design features in combination with P2P trade are examined. Our model minimises the electricity costs of a small community subject to a local supply-demand balance which schedules the operation of RES, grid consumption, battery usage and P2P trade.

The community comprises a set of houses of consumers and prosumers which are heterogeneous both in demand patterns and technology portfolios. The houses are equipped with either a wind turbine, a PV panel, both or none of these technologies. Additionally, the houses have the possibility of storing energy in either a decentralised privately owned battery or a commonly accessible centralised battery. We use historical demand, generation and price data for a community of houses in London, United Kingdom (UK). To understand the value of local P2P trade and battery flexibility, we compare the outcomes of the two proposed market designs to a reference case that does not incorporate either of the two features. We find that the interplay of storage and P2P trade can save up to 31% percent of the electricity costs for a community. Renewables cover around half of the demand of the community when supported by P2P trade and batteries. From this results, we observe a significant increase in self-sufficiency, utilisation of RES and compelling cost savings.

The remainder of the paper is structured as follows: Section 2 reviews related literature and positions in recent research on local market designs. Section 3 describes the proposition of two distinct market designs for the combination of P2P trading and battery storage, this section also details the modelling approach. The case study data sources and modelling results are presented in Section 4. Section 5 concludes and indicates further research directions.

2. Related literature

Although not widely incorporated in today's electricity markets, the direct interaction (energy trading) within a group of P2P prosumers has recently been explored or partially implemented in pilot projects, e.g. Brooklyn Microgrid [5], Enerchain [6], and others.[2] Zhang et al. [7] review these projects. A similar review by Park and Yong [8] details a specific comparison of the applied business models for the different projects in place. These reviews note that the P2P energy trading concept is at a relatively early stage. No consensus exists on what market-regulatory mechanisms and business models should be in place to facilitate P2P trading. Zhou et al. [9] assess the economic performance of three different P2P sharing models and find that a market based on dynamic price rates is worthwhile. Similar results are found by Long et al. [10] who additionally investigated an auction-based P2P method. In further work, Zhou et al. [11] propose a multiagent-based simulation framework to evaluate P2P energy sharing mechanisms. In other related work, a P2P bidding system has been proposed by Zhang et al. [12] for a grid-connected microgrid, and analysed using non-cooperative game theory. The authors conclude that P2P trading bears large potentials for a better integration of distributed energy resources (DER) into the power system, while ensuring the balance between local generation and demand. The feasibility of P2P energy trading in low-voltage electricity networks was investigated by Long et al. [13]. Their paper entails guidelines for constructing future distribution networks for facilitating a P2P trading market paradigm. The impact of novel energy sharing systems on socio-economic structures is analysed in a theoretical framework by Giotitsas et al. [14].

P2P interaction in a residential community needs proper pricing schemes. Fridgen et al. [15] note that 'one rate does not fit all'. They identify twelve tariff structures for residential microgrids, and simulate the response of 100 microgrids to the designed tariffs. Their findings showcase that tariff designs should consist of capacity and customer charges, while averting mere volumetric billing based on electricity use. Tariffs that account for system and energy retail costs would decrease customers' electricity bills while supporting peak-shaving

[1] Prosumers are consumers that produce electricity from privately owned generation technologies.

[2] Pilot projects include among others: Vandrebron, Netherlands (https://vandebron.nl/), The Sun Exchange, South Africa (https://thesunexchange.com/), Elblox, Germany (https://www.elblox.org/), Power Ledger, Australia (https://powerledger.io/), and Piclo, UK (https://piclo.uk/).