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Peer-to-peer flexibility trading of end-users at distribution networks

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Abstract: Large-scale utilisation of small-scale intermittent, renewable energy resources can cause different types of challenges for their owners and distribution system operators (DSOs). This study proposes peer-to-peer (P2P) flexibility trading which can be used to fulfil DSOs flexibility needs in distribution networks as well as help intermittent resource owners to avoid penalty costs. In the proposed trading, peers acting as flexibility buyers can supply their flexibility demanded from the offers of local sellers. As a result, the sellers are also given the opportunity to make profits through the proposed P2P flexibility trading. The proposed method is implemented for a hypothetical local network with several households, and the results of the two P2P trading structures will be compared as well.

1 Introduction

Due to environmental concerns, renewables-based energy resources are increasingly deployed to supply the electricity demand of customers. Besides, small customers/prosumers are going to be equipped with different energy resources such as photovoltaic (PV) panels, electric vehicles (EVs) and battery energy storages (BESs). This is due to, for example, large government subsidies, customer's increased motivation for self-production and interest to decrease their electricity costs. As a result, the intermittent characteristics of renewable resources along with the bi-directional flow of power will cause voltage as well as congestion-related issues in medium-voltage (MV) and low-voltage (LV) distribution networks. The unpredictable active power fluctuations are challenging for the system operators and they can also lead to penalty costs for the owners of these resources. In other words, in real-time, the real-amount of generation from the above-mentioned resources may differ from the scheduled due to forecast error, the variability of these resources, and the uncertainty coming from the complex behaviour of their owners/prosumers. As a result, this deviation should be compensated by measures defined by the distribution system operators (DSOs).

In the future, DSOs will employ different methods in distribution networks for the needed flexibility services. For example, they can apply penalty costs [1] and strict constraints (such as rules or grid codes [2]) to mitigate the challenges and hosting capacity issues related to uncertain renewable resources [3]. The market- or pricing-/tariff-based methods can be also utilised by DSOs to enhance the flexibility of distribution networks, e.g. in the form of dynamic network tariffs aiming to motivate small-scale resources to react to congestions and capacity limitations in distribution networks [4]. In addition, locational marginal pricing is another possibility to provide flexibility to the distribution network [5].

In this paper, it is proposed that the DSO enables to run of a local flexibility market in which prosumers can sell and buy flexibility in real-time. The proposed peer-to-peer (P2P) trading structure could potentially benefit all the players, i.e. buyers (avoid penalty costs) and sellers (flexibility exchanges).

To the authors' knowledge, the proposed P2P flexibility trading at the customer level in distribution networks is a new concept, because the flexibility needs of small-scale end-users/prosumers have not been previously considered.

Moreover, the proposed P2P flexibility trading structure enables small-scale end-users to individually sell their capacity or buy their required flexibility which can empower local communities as well as increase locally the democracy among the peers. Besides, a great amount of DSO-level flexibility needs will be met locally, helping the DSOs mitigate the uncertainties coming from local renewable energy resources.

2 Methodology

At first, in relation to energy trading, prosumers submit the capacities of their available resources to the DSO. These offered capacities can be from:

- Renewable resources such as roof-mounted PV systems and micro-turbines.
- Storage-based resources, such as batteries and EVs.
- Households' controllable loads such as air-conditioning devices.

After the submission of the available generation capacities, the DSO determines the available capacities i.e. the technical constraints (voltage- and congestion-related limits) associated with the distribution system. Hence, the used capacity of each prosumer (which should be equal or lower than the submitted amount) is determined in this stage. The DSO imposes the financial penalty, in case the prosumers cannot stick to the capacities they had promised.

However, the active power produced in real-time may not have the same value as the forecasted amount since most of the demand-side resources are exposed to uncertainties due to their dependency on environmental factors and complex human behaviour. In this regard, the local P2P flexibility trading is proposed to compensate for the above-mentioned uncertainties, help prosumers avoid the financial penalty, and lead the distribution system to resolve its local flexibility issues.

2.1 P2P flexibility trading

Nowadays, P2P trading has attracted attention due to its benefits in increasing democracy among energy peers as well as due to environmental merits by increased utilisation of small-scale renewable resources [6].

In terms of pricing, P2P trading can be categorised into two distinct types [7]. In the first type, peers who are trading with each other determine the prices meaning that they offer the prices they want to trade at. The second type, however, needs to have a centralized pricing mechanism determined by an operator (e.g. Uber). This paper considers the second-type P2P flexibility trading, in which the price of flexibility trading at each time slot is determined by a centralised entity (e.g. the DSO or flexibility operator) so that capacities are the only offers that peers submit for the flexibility trading.

2.1.1 Trading actors: This paper assumes that the main market actors are household end-users/prosumers located in the neighbouring area who have the capability to trade flexibility locally. The main buyers of flexibility are those with uncertain resources whose offers cannot match with the real amount produced in real-time due to environmental factors or changing the owners' behaviour. On the other hand, sellers are households with available flexible resources (e.g. any kind of DER) and those who are willing to make profits by selling flexibility to their own community.

2.1.2 Trading timeframes: The main aim of flexibility trading is to compensate for the variability coming from intermittent energy resources. Therefore, the flexibility trading should be performed in real-time timeframes with short-ranged time divisions so as to ensure the precision and consistency of the offered flexibility. This paper considers that prosumers offer flexibility for the next hour. Their offers are submitted for four timeslots, meaning that the prosumers submit four 15-min flexibility capacity offers for the next trading hour.

2.1.3 Trading models: In the light of flexibility trading, seller j submits its available capacity, defined as flexibility capacity of seller j (P_j), and buyer i submits the flexibility demand (D_i) needed to decrease the difference between the real and the offered amount of their production.

After submissions, peers' flexibility bids will be matched with each other so that, for example, one buyer can trade with several selling peers. Fig. 1 shows how the offered flexibility demand matches with the offered flexibility capacities in the proposed P2P trading model.

In addition, Fig. 2 illustrates the concept of P2P trading of different prosumers with different kinds of flexible resources.

2.1.4 Trading platform: P2P trading requires a platform through which players can submit their flexibility offers. Besides, the information can be shared through it conveniently among users. The platform should have the capability to match buying flexibility offers with the selling ones and settle the offers according to the objective function defined for the system.

for $i = 1, N_i$
- Calculate all possible combination of sellers in the group of 1 to N_j members
- Indicate each group with the number of its members (g) and the combination number (c)
- Calculate capacity of each combination (e.g. $Cap_{c,g}$ is the capacity of combination c of the g-member group)

  for g=1:N_j

  for c=1:N_c

  if D_i - $Cap_{c,g}$ is a positive value
  - Calculate $min(D_i - Cap_{c,g})$
  - Return $min(D_i - Cap_{c,g})$, i, c, g

  end if

  end for

  end for

end for

Fig. 1 *Algorithm of matching flexibility offers of peers*

Simultaneously also the privacy of personal data and security of the system should be maintained.

Therefore, the Blockchain technology has been introduced as a distributed platform facilitating P2P trading for all users [8]. Peers can trade with each other anonymously through the Blockchain account in a way that their privacy would be protected through the use of this technology [9]. Transparency and constancy can be considered as additional features which a Blockchain-based platform can provide. Blockchain technology utilises cryptographic hash functions in order to protect the privacy of input data.

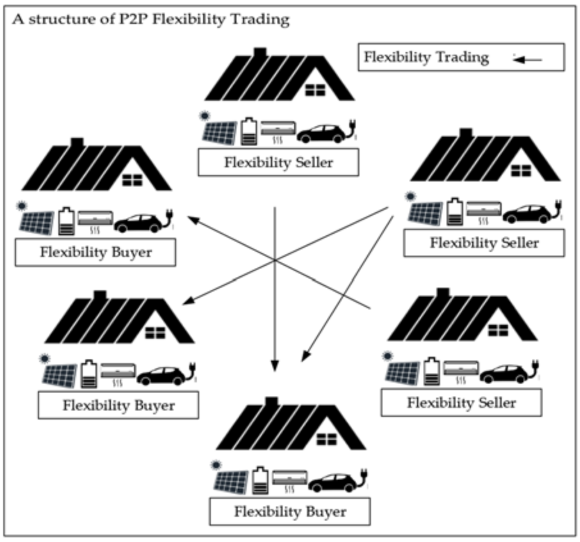

Fig. 2 *Hypothetical P2P flexibility trading structure*

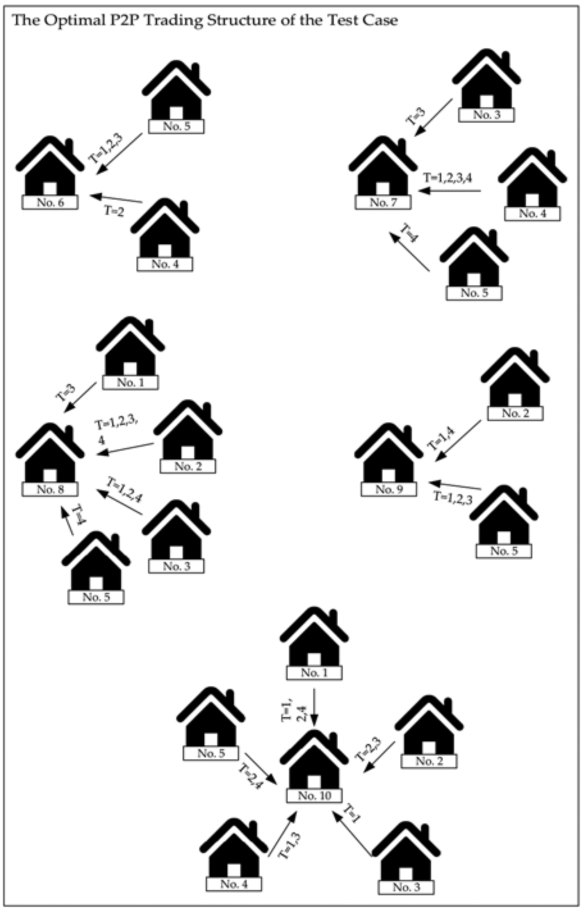

Fig. 3 *Proposed P2P trading structure of the test case*

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Table 1 Amount of unsupplied flexibility demand in the proposed P2P trading structure

Time slots	1	2	3	4
amount of unsupplied demand, kW	0	0	0.84	0.66

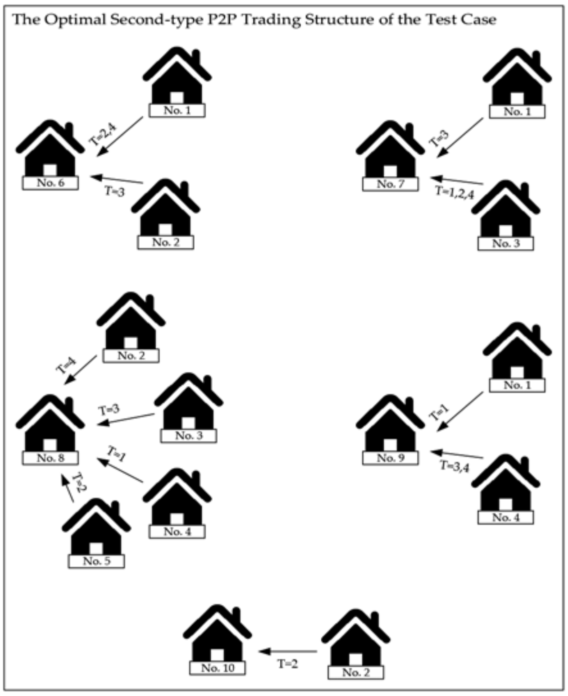

Fig. 4 *Optimal structure of second-type P2P trading*

Further, the connection of transaction blocks in the Blockchain-based platform can ensure that the information cannot be manipulated in this system [9].

3 Simulation results and discussion

The proposed flexibility trading structure is implemented for a local network with 10 residential prosumers. Five of them are assumed to offer flexibility capacities from 1 to 4 kW and the other households submitted capacities in order to supply their flexibility demand which is supposed to be a value between the range of 1–4 kW. In addition, each household submits its offers for four 15-min time slots of the next hour. After the submission of offers, the flexibility demand is matched with the flexibility capacities of peers aiming to supply the flexibility demand of the whole system as much as possible. Fig. 3 shows the optimal trading structures for the proposed test system.

Table 1 also indicates the difference between the sum of flexibility demand and the sum of flexibility capacities which were matched in the proposed P2P trading. In other words, it shows the amount of flexibility demand which was not able to be met in the proposed P2P trading structure. The results indicate that all of the flexibility demand was supplied locally except for time slots 3 and 4.

In this paper, CPLEX solver of GAMS software has been used in order to solve the P2P trading problem (which took 0.05 s). Although the time-related latency does not seem to matter in the local environment with a limited number of prosumers, it may cause problems for the system with a large number of flexibility sellers and buyers since time slots in which flexibility is traded should be smaller compared to those used in the energy-based trading. Therefore, a case in which each flexibility buyer can trade with only one peer in each timeslot was considered. This means that the flexibility demand should be equal or lower than the flexibility capacity offered by the seller peer.

Table 2 Amount of unsupplied flexibility demand in the second-type P2P trading structure

Time slots	1	2	3	4
amount of unsupplied demand, kW	4.19	1.64	2.54	2.86

To analyse the impacts of the second model, the same solver was adopted to run the trading optimisation (took 0.015 s). The optimal structure of the second type and the unsupplied amount of flexibility are illustrated in Fig. 4 and Table 2, respectively.

When comparing the results obtained from Tables 1 and 2, the unsupplied flexibility demand of the second-type P2P trading is considerably higher in comparison with the proposed type. In other words, although the latency for trading decreases from 50 to 15 ms, the second-type structure has unsupplied demand in all time slots which cannot be met.

4 Conclusion

This paper focused on the problem of flexibility trading of small-scale residential prosumers located in the distribution system. In this model, the flexibility demand was fulfilled locally while some prosumers made profits through selling flexibility in real-time. In the proposed model, one buyer was able to trade with several sellers in order to supply its flexibility demand. The results of the proposed P2P model are compared with the results of another model in which a buyer can trade flexibility with just one seller. In the simulation results of the second model, in which a buyer can trade with only one seller in each timeslot, there was a considerable decrease in the trading latency. However, it was not able to supply flexibility demand as much as the first model was. Hence, based on the market objectives and the number of local players, a much more appropriate P2P settlement can be achieved for flexibility trading with the proposed P2P flexibility trading.

5 Acknowledgments

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