# LOCAL ELECTRICITY MARKET DESIGN FOR PEER-TO-PEER TRANSACTIONS WITH DYNAMIC GRID USAGE PRICING

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## Abstract

This paper presents the market concept of a local peer-to-peer (p2p) marketplace that enables small consumers to buy electricity different from their local utility and offer their generation for sale. The marketplace considers network constraints to ensure technical feasibility of local market transactions and the grid effect of the trades are priced by a dynamic network usage tariff (DNUT). Thus orders at the local market include the related network connection point. Such a local market can provide implicit congestion management and voltage regulation services for distribution system operators.

## 1   Introduction

Small consumers, households are not able to participate either at current wholesale or at flexibility markets mainly because of the relatively high one-off costs and minimum bid sizes. Development began in two directions to solve this issue: aggregation (bottom-up) and market development for local use cases (top-down). The former one is based on grouping small parties and representing them at current markets where the participation conditions such as minimum bid size cannot be met individually. Whereas the latter approach aims at the introduction of new, specialized marketplaces for small consumers.

Furthermore, small consumers are connected to the distribution system where the need for flexible sources is growing, too. Aggregating household-size flexibility to provide TSO ancillary services is yet more difficult as such services are defined with strict and rigid requirements (e.g. continuous availability, short time to respond). Instead, the proposed local market concept considers what is preferable for the local grid operator and is not based on direct activation of flexibility.

In the framework of the H2020 INTERRFACE project, a local market platform is being developed and demonstrated that is aware of the grid effects of the trades. A complementary trading platform is targeted to facilitate p2p energy transactions between small users and to use DNUT to motivate market players to carry out network-advantageous transactions. The trading and settlement rules are designed primarily for low and medium voltage (LV and MV) networks, they build upon the radial structure of the topology.

One advantage of the proposed local market concept is that nothing is changing for non-participating grid users, while active users can benefit from the local market trading. The local market trading platform and the current retail market are planned to operate in parallel. The consumer can participate in both markets. Its energy demand can be partly procured from the local market, while the remaining need is settled by the supplier. Local market participation is not obligatory but open for all local grid users (consumers, prosumers, producers and storage owners). Local trading is incentivizing as it enables an opportunity for buying electricity low and selling it high. Also, soft effects can promote it, such as community-forming, the choice of buying from the neighbour or a low-carbon supply, and independency from the retailer (partly self-sufficiency).

Local market trading supports on one hand the local usage of the near generation reducing grid loss and the reverse flow in radial grids as well as helps to accommodate distributed renewable generation. Moreover, economic benefits of local market trading incentivize for trading at a market that is aware of the grid constraints and thus provides implicit congestion management or even voltage regulation service for the DSO.

Several local markets have been proposed in the literature. However, most are virtual (only trading) arrangements and do not consider the grid behind [1]–[3]. The Brooklyn microgrid [1], for instance, is similarly a continuous local p2p market, but is implemented using blockchain. It also aims at RES integration with local energy consumers and provides flexibility for the DSO. However, the DSO's flexibility activation here is explicit unlike in the proposed market model, where DSO aspects are considered by the market algorithm based on load flow-like investigations. Another similarity to the hereby described p2p local market is that both markets can operate in addition to the conventional supplier model. Sonnen [2] is a virtual community where prosumers equipped with PV, battery and a corresponding battery energy management

system (SonnenBatterie) are connected. The community provides balancing services for the TSO that is not the case in the proposed INTERRFACE local p2p market. Sonnen is the supplier of the consumers in the community, while the INTERRFACE local market consumers can choose any suppliers freely as a complement to the local market. A third example is the Powerpeers local market platform [3]. On this market, if any need cannot be met from the local trades, Powerpeers supply the consumers as a retailer.

## 2. The proposed local market concept

This section describes the high level concept of the local market starting with its attributes and timeline to examples.

### 1.1. Attributes of the local market

A continuous trading platform is being developed for the local market in contrast to the usually auction-based local markets ([4]-[8]). When hitting an order, one should be able to consider both its price and its owner. Therefore, the trading platform is suggested to be non-anonym as default in order to emphasize its p2p characteristic. However, it can be anonymous for example due to GDPR issues. Further enhancements could be delivered if bids can be flagged as anonymous – this could create additional benefits, through increasing the pool of available matches. Also as default, there is no automatic execution of matchable orders by the platform, the bidders need to hit the preferable orders. In this case however, market participants can use automatic bidding strategy if a well-defined API is available for the platform. Nevertheless the platform can be also operated enabling automatic pairing of orders based on the order prices.

The subject of transactions is energy delivery in a defined period. The timeline of the suggested platform is similar to a continuous intraday platform using only quarter-hour energy products. There are two main differences compared to the standard European intraday platforms: no automatic execution as default (it is optional) and the clearing price is different for seller and buyer because of the dynamic network usage tariff. For each transaction on the local market a DNUT is calculated based on the location of the partner, the current state of the network and the flexibility demand from the DSO. DNUT is automatically calculated and added to the energy price of the submitted order, hence the total order prices visible for other local grid users are the energy bid prices modified by the DNUT. Full bid prices are different in different nodes of the local grid leading to different nodal views of the order book.

The proposed p2p local market is expected to be operated by an independent third party as default to fully fit into the European market environment and endeavour. Although, DSOs could be also imagined to operate such a market as having many connections to it. First of all, usually they owe the settlement meters and are responsible for the metering instead of a third party metering operator. Secondly, they are notably effected by the dynamic network usage tariff, and they have the chance to alter network usage tariffs in the local grid, possibly with the approval of the regulator. Thirdly, they face

the distribution system problems (e.g. voltage problems, congestions, overloading of equipment) to be handled by the local market. The local market operator is also responsible for the settlement related to the transactions on the local market.

### 1.2. Timeline

The schedule of the suggested platform is similar to a continuous intraday market with quarter-hourly products. For each 15-minute delivery period, one product is defined. Gate-opening for bid submission is in the afternoon of the previous day (D-1) for all products (e.g. at 5 PM). When the gate is opened, new orders can be placed by the market participants that can be also hit by other bidders. Each trading yields an energy exchange in the delivery period of the products. The trading period of each product is suggested to be closed close before the delivery time - maximum 1 hour before.

The executed transaction obliges the buyer and seller participants to consume and produce the amount of energy specified in the transaction. In the case of missing this obligation (metered consumption and/or production is less than the settled), the relevant market player is subjected to punishment at the local market.

### 1.3. Dynamic determination of network usage tariff

End-user retail tariff consists of energy price and network usage tariff. The total transactional price on the local market platform has a similar approach. It consists of the energy price determined by the bidder and the dynamic network usage tariff calculated by the platform. The local DNUT is presumably lower than the general network tariff, since the local transactions do not use high voltage networks (nor the MV grid in the case of an LV market). Therefore, DNUT is a measurable incentive for local users to trade locally.

DNUT calculation is an innovative method, which relies on load-flow approximations, as follows. A base-case for load and generation is forecasted for every 15-minute interval. It models under the assumption that users have a default consumption and production independently from the local market prices, even in the absence of a local market. Secondly, using the base-case flows, voltage-, current-, and loss sensitivity factors are calculated by load-flow simulations. The effect of trades on the system state (nodal voltages, branch currents, total loss) are estimated using the above defined sensitivity factors.

These values are used to calculate the DNUT through weighting and fulfilling (one or more) predefined criteria according to the schedule of the demo:

- Nodal voltages should be in a tolerance range [9].
- Network loss should be minimized.
- Branch currents are limited by thermal constraints.

The reason for not using load-flow for network condition calculations is because it is computationally intensive. Thus it would be time-consuming for continuous market operation, especially when considering numerous orders, and more than a hundred prosumers, as for each submitted order one load flow would calculate the DNUT for only one node. Moreover, DNUTs must be recalculated after each trade concluded. The

presented DNUT method can consider the following aspects (directly or indirectly):

- network loss,
- nodal voltage,
- asymmetry level (through voltages and loss),
- congestion of network elements (branch currents),
- distance of partners (through voltages and loss),
- time of network use (present in the market through volume and price of orders, but additional DNUT element can be designed based on the system operator's need).

As a consequence of dynamic network tariff, the settlement price on each connection point might differ. However, this does not mean that nodal pricing is used, since prices are not strictly connected to the nodes, rather to the transaction and the two partners in the transaction. There are different options regarding the payment of the DNUT:

- The aggressor (that hits the order) is charged the full amount of network tariff.
- The trade partners share the costs 50-50%.
- The market participant placing the order is charged a fixed price as DNUT. The full cost is evaluated at order hitting, and the remainder is paid by the aggressor.

### 1.4. Examples for the DNUT

Examples are provided to show the operation of the proposed market. Only the cost of network loss as DNUT component is considered in these examples for the sake of simplicity. Energy flows and transactions are coloured differently.

Firstly, assume a base network state for a given delivery period. It consists of the planned topology of the network and the forecasted energy flows between the local participants and the main grid. These base-case flows are denoted with blue arrows in Figure 1. HH represents a household consumer.
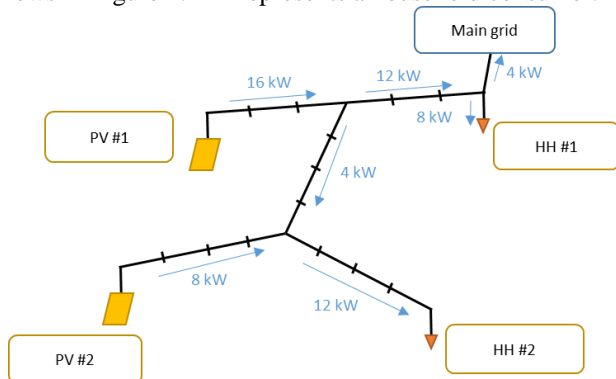


Figure 1: Example for a base-case flow

Each bid placed by local participants has a base (energy) price parameter defined by the bidder: how much they are willing to pay, or they would like to be paid for each offered kWh. The clearing price of each bid is modified with DNUT, and these modified values are shown to the other participants. Note that the settled DNUT depends on who will hit the bid. For each network point, DNUT is calculated by answering the following question: how much would the network cost be if the bid was hit on that network point. The transaction is not simply added to the base-case flows. In fact, the base-case is decomposed to

the assumed transaction (denoted with green), and the remaining flow (still denoted with blue), as in Figure 2. The loss cost of the assumed transaction is calculated from the difference of the two cases: the total loss cost of the base-case (blue, Figure 1), and the total loss cost when the transaction is subtracted from the base-case (blue, Figure 2).
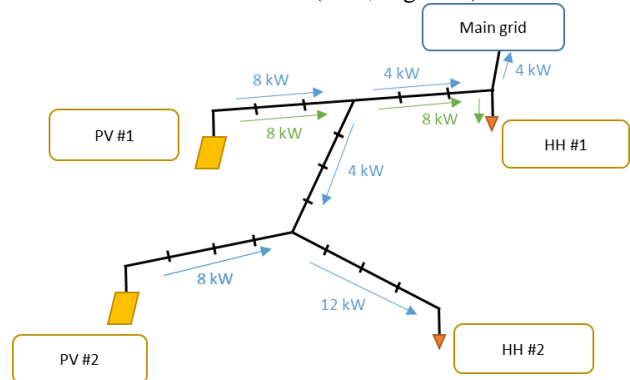


Figure 2: The procedure of DNUT calculation if the 8 kW sale order of PV#1 was hit by HH#1.

A local-market energy transaction may exceed the base-case flows, hence resulting in an overflow (denoted with red in Figure 3). The overflow is always modelled between the main grid and the market participant whose forecast was wrong. Base-case flows are modified properly if such a transaction is executed. After the modification, the procedure of DNUT calculation is the same as in the first case. The main grid has a different sale price (SP) and purchase price (PP) as marked in Figure 4. In this example, the aggressor pays the whole amount of network tariff. Although it might look unfair, this way both partners pay and get the price that is shown on the platform.
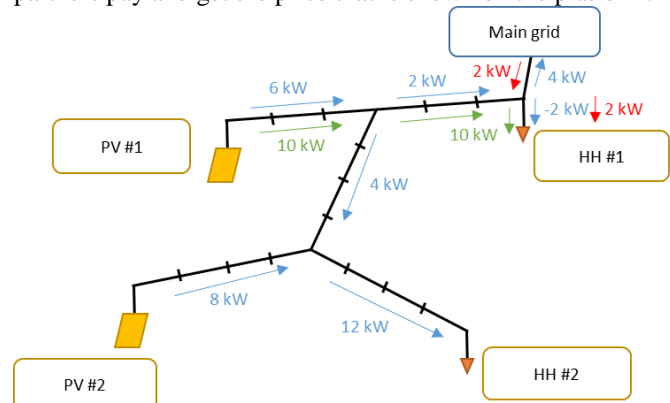


Figure 3: The procedure of DNUT calculation if the 10 kW sale order of PV#1 was hit by HH#1.

However, HH#1 is forecasted only to consume 8 kW; therefore, base-case flows have to be extended with 2 kW from the main grid to HH#1. Then DNUT is calculated from the difference between the network cost with blue, green and red flows and network cost in case of only blue and red flows. After delivery, the real flows can be determined from the meter data (black in Figure 4). Furthermore, these can be used when forecasting the base-case flows for the next day.
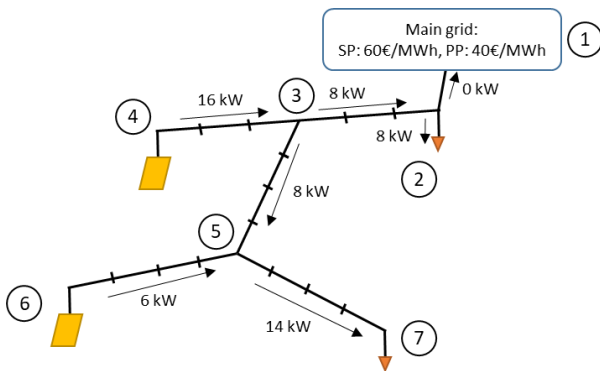
Figure 4: Metered physical flows

Figure 5 gives a third example. Main grid supply price is 60 €/MWh (with non-local grid tariff) while the purchase price for roof-top PV is 40 €/MWh for every participant.
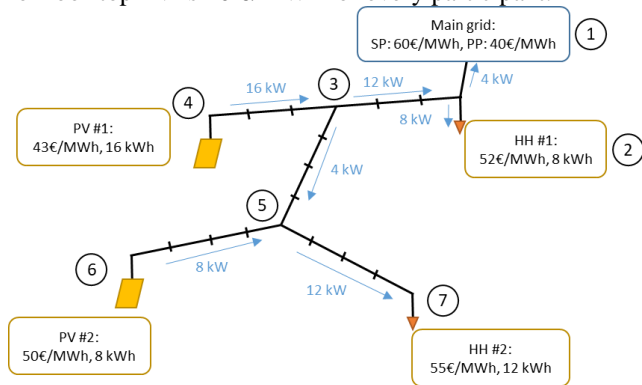


Figure 5: Example with 2 PV sale and 2 HH purchase orders

The submitted bids at the other nodes appear as in Figure 6. Note that no transaction is executed yet, only the full prices are calculated for each node, modifying the energy bid price by the possible DNUT. If PV#1 hits the order of HH#1 whose limit purchase price is 52 €/MWh, PV#1 pays the DNUT as being the aggressor. The DNUT is 1.688 €/MWh considering the loss effects of the given transaction. This is subtracted from the original income, which results in a lower (50.312 €/MWh) price. The value of DNUT is suggested to be collected by the Local Market Operator. HH#1 pays 52 €/MWh and PV#1 gets only 50.3€/MWh. So the limit price of the purchase order of HH#1 is 50.3 €/MWh in the node of PV#1.

The settlement of the local market transactions is based on the metered values. Each concluded energy trade is subtracted from the measurements and the remainder is settled according to the retail contract. A balancing-like, local financial sanctioning mechanism is suggested to avoid negative remainder (metered consumption is less than the contracted volumes). Apart from this sanction, grid users can also pay balancing costs according to their contracts. Small consumers are assumed to have partial supply-based contracts with no direct balancing costs, while larger customers have schedule-based contracts with full balancing responsibility. Therefore, customers with schedule-based contracts are motivated to inform their BRP about their schedule change. Also, local market trades help avoiding balancing costs. It is the customers' responsibility to inform their BRP if necessary.
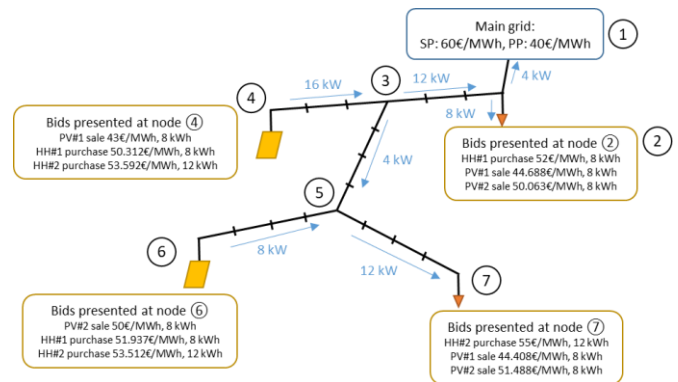


Figure 6: The bid prices at different nodes

## 4 Conclusion

A local p2p market concept has been developed that considers the grid effect of the trades and asset load limits. The concept fits for small consumers of the distribution grid as well as the aspects of the distribution system operator. It enables smaller distribution grid flexibility to integrate distributed RES.

## 5 Acknowledgements

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