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P2P local market concept with dynamic network usage tariff via asset enablement – Horizon2020 project demo experiences

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Abstract. With the growth of renewables, the increased interconnection of European grids, the development of local energy initiatives, and the specific requirements on transmission system operator (TSO) – distribution system operator (DSO) cooperation as set forth in the different Network Codes and Guidelines, TSOs and DSOs face new challenges that will require greater coordination. The European Commission adopted legislative proposals on the energy market that promote cooperation among network operators as they procure balancing and other ancillary services and provide congestion management. Therefore, this creates the need for a specific project such as the H2020 INTERRFACE project, having the greater coordination between TSOs and DSOs as its core objective. In this project, one of the demonstrations is a local asset-enabled energy market to provide data-driven, simulation-based results, with a realistic market setting. There the transactions beneficial for the distribution grid are facilitated via dynamic pricing (DNUT – dynamic network usage tariff).
In the demonstration of a local market that runs based on data, provided from 3 sites (2 Hungarian, 1 Slovenian), local distribution system operators are involved to provide grid and consumption/production data. This paper discusses the first results from one demonstration site, which contribute to the development of local P2P markets. It also facilitates the introduction of grid calculation based dynamic tariffs by providing practical results from the cooperation of research entities and DSOs in the H2020 INTERRFACE project.

Key words. P2P trading, local market, flexibility, asset-enablement, microgrid

1. Introduction

The integration challenges of renewable energy transform the entire value chain of the power sector. The future market model can be differentiated on several levels: it could be dependent on the amount of energy, transmission distances, the number of participants, etc. [1], but the decentralization is inevitable. Local energy generation is becoming widespread nowadays, not only for economic reasons, but also as a representation of independency and decent behavior. Peer-to-peer (P2P) markets aim to provide trading opportunities between a large number of market players, even when buyers and sellers are fragmented. Also, auctions on P2P markets are a flexible solution, allowing prices to respond to market conditions [2]. This local market structure is appropriate to enhance the customer's access to new energy-related market activities, which therefore could play a part in the energy transition.
The players on this marketplace shall submit their bids (if they are buyers) or asks (if they are sellers). These shall include information on the quantity of electricity and the network connection point where the exchange will take place. Consumers may buy electricity from sources different than their local retailer and can also offer their household generation for sale. The introduction of this market structure is feasible in parallel with the conventional one. There is a possibility to handle services through such P2P markets [3]. If the trading is not done between two consumers, but between a consumer and a DSO, the DSO can create a group of bids and asks, thus creating means of flexibility. Such flexibilities can either be used by the DSO for grid services or aggregated/forwarded to the TSO, depending on the wholesale TSO-DSO coordination scheme. The DSO and the TSO also participate in the market, and they can both behave as bidders: by specifying and pricing their flexibility needs (and the price they are willing to pay for it), they can enhance the utilisation of local sources. This latter aspect is also necessitated by the merging of traditional DSO and TSO operations, which converge previously separated tasks, thus the demonstration could provide a way for testing this aspect as well. The toolset of the INTERRFACE T6.1. demonstration which we discuss in this paper is comprised of an automated marketplace and a grid modelling process. This marketplace is based on the P2P concept and provides the possibility to create local energy transactions by simulating the behaviour of market participants in line with different bidding strategies from previous research [4-6]. The load and generation datasets are derived from DSO databases to create realistic reference situations. Then the effects of the different bidding strategies can be analysed. The demonstration aims to examine the cooperative use of these two elements of the toolset.
3 DSOs are involved, 2 from Hungary and 1 from Slovenia. The DSOs offered unanimous measurement data about the demonstration locations and provided inputs to create a new dynamic network usage tariff (DNUT). The concept of

dynamic tariff based on forecasting the constraints by network calculation is not widely implemented in practice [7]. Integrating such solution with the P2P concept is generating new ideas as frameworks are being developed [8-10]. In these demonstrations, prosumers can buy and sell electricity either from this local market (P2P context) or from the retailer in the already existing framework. In addition to the P2P context, the project proposed a novel dynamic network usage tariff scheme (DNUT). The grid fees for each transaction are calculated by the actual effect on the infrastructure (losses, voltage limits, overload, asymmetry effects considered). To calculate such, the project developed a modelling approach tailored for medium voltage (MV) and low voltage (LV) networks, which is appropriate for steady-state analysis. Since P2P markets have a large number of expected bids, and the calculation must pair a DNUT (grid effect) to each bid, a sensitivity-factor based simplification is proposed instead of running a large number of load flows. With these tools, end users can behave as “market participants”, dynamic pricing can be used efficiently, and the effects of network asset constraints can also be taken into consideration. Data used for the demonstration will be provided by affected DSOs, while the behaviour of consumers is to be examined by the involvement of consumers in the affected DSO service areas.

The demonstration focuses on upscaling the role of customers and creating new services and market rules within the local marketplace. These tools will be part of the Interoperable pan-European Grid Services Architecture (IEGSA); thus, their collaborative operation could be demonstrated, and mutual benefits could be exploited. The IEGSA has to provide an interface for consumer participation, an access for DSOs, and a pool for asset condition data.

The paper is organised as follows. Section 2 overviews the simulation architecture of the demonstrations, while Section 3 describes the key elements of the developed P2P market. Section 4 discusses the simulation results from one of the demonstration sites, while Section 5 summarizes the main conclusions achieved by the project so far.

2. Description of the simulation framework

The H2020 INTERRFACE project aims to advance in the development of TSO-DSO cooperation and offer new possibilities for customers to be active participants in novel energy markets. The demonstration introduced here tests a P2P market that is operated in parallel with the regular retail market and discusses the DNUT concept. Figure 1 depicts the architecture of the simulation environment. The red lines indicate the flow of technical data, while the black lines represent the market process steps and data sharing.

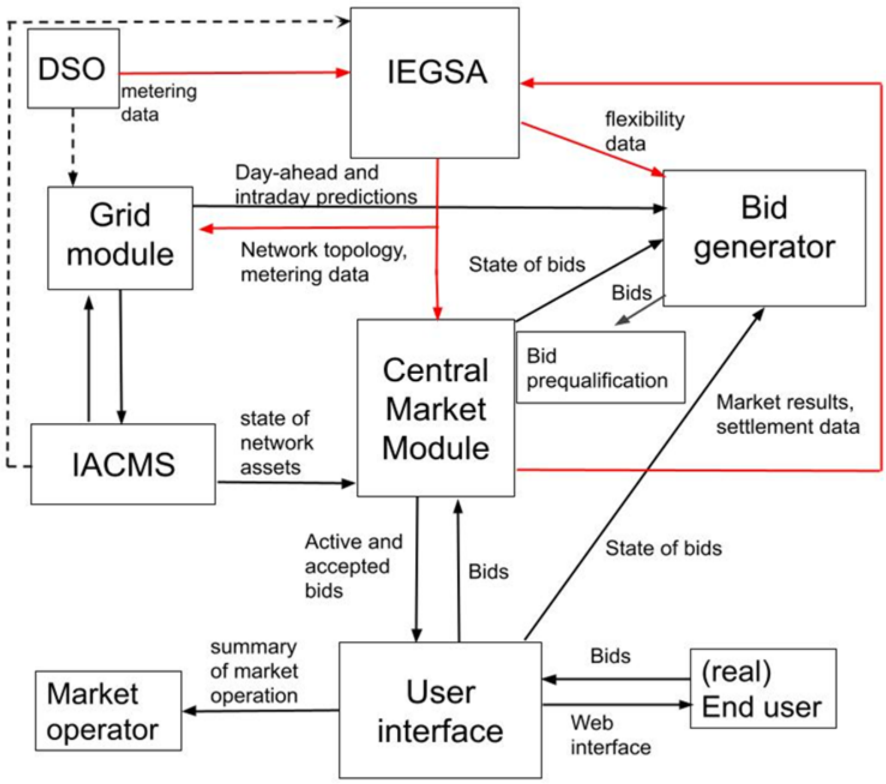

Fig. 1. Business architecture of the demonstration

In the upper left part, the input data is described. The participating DSOs provide 2 types of data:

Metering data (active and reactive power) for customers. This also includes the local generation by photovoltaic (PV) household-sized power plants on the LV network. The demonstrations differ by the availability of 15-minute resolution data (from smart meters). If a customer does not have a smart meter, a synthetic load profile is used based on the yearly consumption and statistical data from the DSO.

Grid data: the DSOs provided all the relevant data from the geographic information system and other expert systems (to have further technological data) to the "**Grid module**". Due to the fact that most of the DSOs have not introduced the common information model data format yet, the Grid module processes the input data tailored to each DSO and creates a unified network model. This includes the topology (graph representation, connection description between the elements), the parameter tables in the background (consisting e.g., of impedance values, short-circuit power etc.) and attribute tables for the consumers/prosumers (limits for operation and identification to connect with the input meter data.). The module creates a structure that is appropriate for steady-state analysis of power systems (load-flow calculations) and calculates voltage/current sensitivities for vertices and edges. This is necessary due to the possible large number of P2P transactions: the effects on the grid must be calculated quickly to provide DNUT for each transaction. This approach makes the calculation feasible with a proper level of accuracy. The base-case is calculated by a load-flow (if no P2P transaction is considered). Section 3.C provides further information on the DNUT calculation.

The so-called "Integrated Asset Condition Management System" (**IACMS**) is a tool that provides accurate models for specific grid elements, such as transformers and cables. This is based on the actual and historic loads, temperature and historic operation data. In this paper, the IACMS is not discussed in detail; however, the architecture figure contains it for the sake of completeness. **IEGSA** provides a generalization to connect to further solutions developed by INTERRFACE, data sharing possibilities for customers, the TSO and standardization of the environment.

The **Central market module** realises a P2P market, which was described in detail in a previous publication [11]. This is basically a marketplace where supply and demand bids can be placed and hit by participants. Since the conventional retail market is operating in parallel, this is considered as an extension, a further possibility to participate voluntarily. (Trading brings obligations and balancing responsibility as well; however, the technicalities of the parallel market operation are not in the scope of this paper.) The local market is similar to an intraday wholesale market: the energy (min. 1 kWh) can be traded continuously for 15-minute periods, starting from the previous day until gate closure. The settlement is carried out after the delivery by measurements.

Since the framework provides simulations based on real-life input data, bids are generated by an algorithm which is the "**Bid generator**". These artificial bids were designed by different strategies. The bids have attributes such as type (supply or demand), timeframe (which 15-minute period is considered), volume (kWh) and unit price (€/kWh). There are day-ahead and intraday bids. The difference between those is that the latter have lower forecast error. The schedule is based on the metering data provided by the DSOs and uses simple statistic methods. As this paper focuses on the discussion of the demonstration, the estimation process is not described in detail here. The bids are also **prequalified** (e.g., if a prosumer's contracted power is 5 kW, but tries to consume more, a bid will be rejected). The **user interface** of the framework provides access to the testers (**end-users**) in the project (participating DSOs, researchers, volunteering market participants) and for the **market operator** (the INTERRFACE participants during the demonstration). There is a possibility to put in bids as participants to the market by volunteers in addition to the artificial bids.

The simulations provide the following results:

- Base-case flow

Voltage, current and power data of the network, corresponding to the 'base case' – without any local market activity.

- Local market results

Voltage, current and power data, if both local market and non-local market transactions are considered simultaneously. In this case, we assume that e.g., in the case of consumers, half of the local market trading volume is subtracted from the 'standard' consumption, covered from non-local sources.

- Bid acceptance ratios

Resulting acceptance ratios of single bids.

- Day-ahead matching results

Results of the matching, corresponding to day-ahead bids (we distinguish between day-ahead and intraday bids in the local market), and power values corresponding to these matchings (as additional information and for the reproduction of the simulation).

- Only local market results

Voltage, current and power data of the network, corresponding to purely local market activity (no power in/out flow from/to outside the network).

- Settlement

Results corresponding to settlement, the resulting incomes and costs of market participants.

- Stats out

The file includes post-processed measures (key performance indices) of the simulation results, which potentially serve as a basis for the overall evaluation.

For the initial results evaluation phase, the "stats out" file provides a summarized result.

The demonstrations started in 2021. Currently, DSOs are analysing the output results and provide feedback to the project team. This paper discusses the first feedback provided by a Hungarian DSO.

3. The proposed local market concept

This section describes some technicalities of the local market, the timeline of the trading, and introduces aspects of the DNUT. The scope of this section is to provide sufficient technical background information to process the simulation results of Section 4.

A. Attributes of the local market

A continuous trading platform was developed for the local market in contrast to the usually auction-based local markets. 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-anonymous 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 an automatic bidding strategy if a well-defined API is available for the platform. Nevertheless, the platform can be also operated by 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 DNUT.

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. Section 3.C further describes the DNUT technically.

The proposed P2P local market is expected to be operated by an independent third party by default to fully fit into the European market environment and endeavour. Although, DSOs could also be imagined operating 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 affected 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.

B. Timing of the P2P market operation

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 just before the delivery time – maximally, 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.

C. 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 can be 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 these 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.
- Network loss should be minimized.
- Branch currents are limited by thermal constraints.

The reason to avoid 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.

Figure 2 depicts the calculation process for DNUT. At first, a matrix is created with the size of the prosumer number and filled with zeros. Then, the algorithm starts to add prosumers one-by-one (prosumers < number of prosumers branch) and calculates the prosumer's effects based on the voltage sensitivity factor and current sensitivity factor (VSF and ISF respectively). Then if all the prosumers are present, the effects of any bid can be calculated by subtracting the effects from the base-case flow (based on the sensitivities). Then the algorithm assigns the DNUT for the transaction.

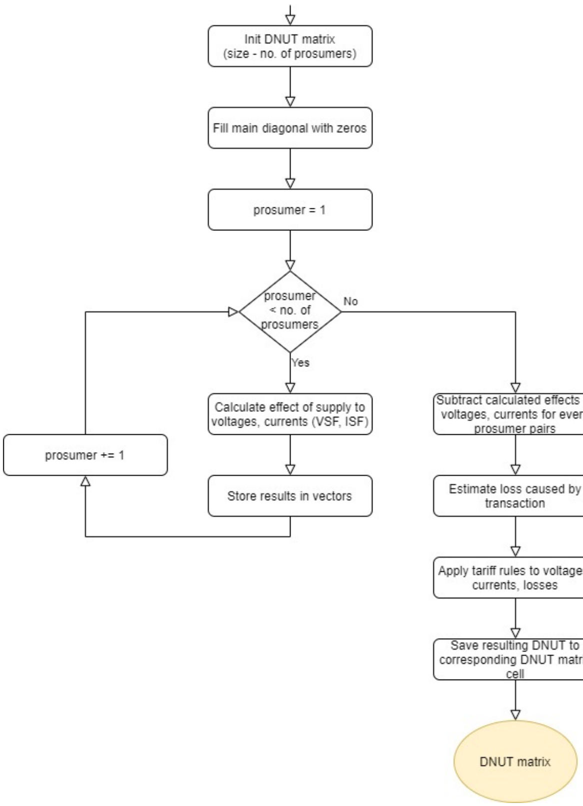

Fig. 2. Flow-chart of the DNUT calculation

4. Simulation studies

The simulation studies have been performed in a MATLAB environment. The demonstration site is an MV/LV transformer area of a contributing DSO. A 400 kVA transformer supplies the area, where 142 consumers are connecting with 180 metering points. The large difference is due to a special tariff applied in Hungary for fixed heat storage devices (mostly boilers). The DSO offers a reduced tariff to such through a separate meter but have the possibility to switch of the supply during peak hours (regulation describes the rules for switching in detail.). 35 meters present due to this special tariff. There are 11 prosumers with the installed cumulative PV capacity of 74 kW_p. Nearly all of the consumers have smart meters (only 5 of the 180 was estimated by a synthetic load profile). The overall loading of the transformer is around 67%, which is quite high in Hungary. Figure 3 depicts the structure of the LV grid, which consists of approx. 2.5 km of overhead lines. The electrical data for the model was provided by the DSO.

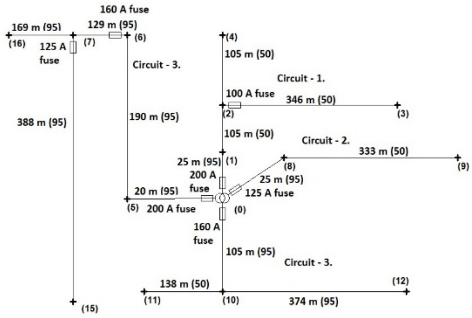

Fig. 3. Flow-chart of the DNUT calculation

During the evaluation, the examined 56 output parameters were examined for the three BC intervals: BC Winter 04. 01. 2021—24. 01. 2021; BC Spring 05. 04. 2021–26. 04. 2021; and finally for the period 30. 08. 2021—05. 09. 2021. Where there was a discrepancy, an attempt was made to identify the cause and to evaluate the effect. Thus, a selective list was made for the evaluation, which is intended to show which scenario is the most favourable for the DSO. Only some parameters (loss, voltage change) were considered here. In the further subchapters these values are evaluated and presented as diagrams. Figure 4 contains the different scenarios. Cells with a yellow background and question marks were not considered in these simulations. The main differences between the scenarios are the estimation process (availability of smart meter data and grid measurement), DNUT calculation (losses, IACMS, voltage regulation or avoiding the overloads is included), asymmetry (scenario 15), order types (bidding) and the sharing of the DNUT. The DSO storage and congestion forecast scenarios are not discussed in this paper.

Table I. Scenario summary

Number	Start date	End date	Name (DNUT change / data availability change)
1	2021.01.04	2021.01.24	Base
2	2021.07.12	2021.07.25	Grid measurements included in the estimation
3	2021.04.26	2021.05.16	Shared DNUT
4	2021.05.17	2021.06.06	Fix DNUT for bidder, remaining for aggressor
5	2021.06.07	2021.06.20	Congestion management limit
6	2021.06.21	2021.07.11	Congestion management limit + punishment
7	2021.01.25	2021.02.21	Voltage limit in the DNUT
8	2021.02.22	2021.03.14	Voltage limit with DNUT punishment
9	2021.07.26	2021.08.15	Losses + congestion management
10	2021.03.15	2021.04.04	Losses + voltage limit
11	2021.09.06	2021.09.26	Losses + congestion management + voltage limit
12	2021.09.27	2021.10.17	Extra flexibility offers added
13	2021.10.28	2021.11.07	DSO storage use case 1
14	2021.11.08	2021.11.21	DSO storage use case 2
15	2021.11.22	2021.12.05	Asymmetry consideration test
16	2021.12.06	2021.12.19	Non-anonym bids, without automatic pairing
17	2021.04.05	2021.04.25	Base case for spring
18	2021.08.16	2021.09.05	Base case for summer
21	2022.01.03	2022.01.24	DSO congestion forecast test with increased base case flow

The maximal loss per traded volume ratio *(LpTVr)* in OLM (over trading periods where only local market (OLM) is active) [%] varied between 0% and 1.2% as displayed in Fig. 4.

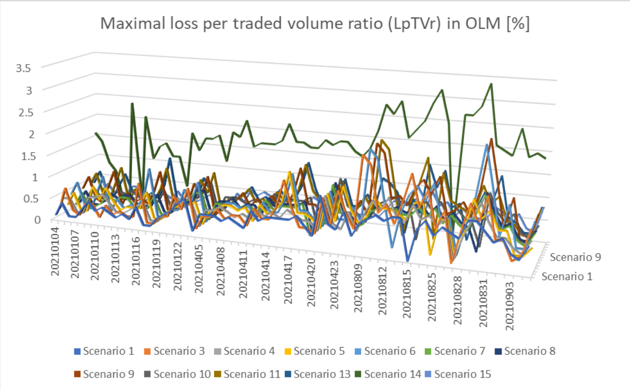

Fig. 4. Maximal loss per traded volume ratio

Figure 5 shows the maximal voltage deviation (VD) in OLM [V] (over all prosumers and periods) varied between 1 V and 9 V. Mostly there are no significant differences between the scenarios here either. There is, however, one significant difference between the scenarios – as in scenario 14 the values are significantly higher, and at this level the voltage deviation could have a significant impact on the network. Determining the cause of this phenomenon requires further examination.

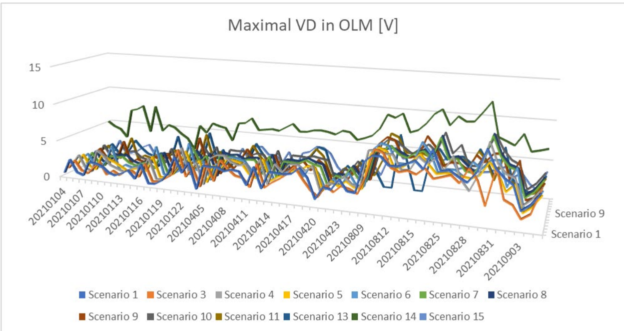

Fig. 4. Maximal voltage deviation in OLM scenario [V]

The first results show the capability of the simulation framework on assessing P2P local market demonstration results. DSOs evaluate the results and give feedback on which strategies should be further investigated with new bidding strategies.

5. Conclusion

This paper described a P2P local market concept which is applicable for distribution networks. The opportunities with the proliferation of such local P2P markets were described. The INTERRFACE simulation framework was introduced from the viewpoint of demonstration analysis. The basic concept of the market operation and DNUT was presented.

Thanks to the dynamic network usage tariff (DNUT) facilitating transactions which result in desired flows according to the actual state of the distribution grid, several measures describing the efficiency of operation are expected to improve during the simulated operation of the local market. The loss compared to total trading volume is expected to be reduced.

Line congestions and near-overload of system components (e.g., transformers) are expected to be alleviated, in an ideal case, the load of the network will be more balanced. Voltage regulation measures are expected to improve (in the case of the corresponding DNUT calculation – the DNUT does not always include elements related to voltage stability).

The results showed that the framework is capable of providing data for evaluation of the local P2P market. However, in the first scenarios, there are not large differences due to the bidding strategies. Further simulations with increased activity could show the potential of the developed tool.

The proposed local energy market provides an opportunity for participants to translate their flexibility potential to local transactions financially beneficial for them. If a consumer participant is ready to reschedule some of its peak load, and energy is available at the local market at an appropriate price, the peak-shaving of overall consumption patterns may be realized via the result of such transactions.

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