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Impact of Producer's Offering Prices in Peer-to-Peer Electricity Trading on Power Flows in Distribution Grid

Lin Herenčić
Department of Energy and Power Systems
University of Zagreb, Faculty of Electrical Engineering and Computing
Zagreb, Croatia
lin.herencic@fer.hr

Perica Ilak
Department of Energy and Power Systems
University of Zagreb, Faculty of Electrical Engineering and Computing
Zagreb, Croatia
perica.ilak@fer.hr

Ivan Rajšl
Department of Energy and Power Systems
University of Zagreb, Faculty of Electrical Engineering and Computing
Zagreb, Croatia
ivan.rajsl@fer.hr

***Abstract*—The business models for peer-to-peer electricity trading are emerging but number of challenges still must be solved to allow large-scale deployment. The aim of this paper is to investigate effects of producer's offering prices on power flows within a distribution grid where peer-to-peer electricity trading is simulated. The peer-to-peer electricity trading is simulated as a near real-time auction-based local electricity market and tested on the IEEE European low voltage test feeder. That way, the effects on peak load requirements and local energy balance are studied. The results point out that peer-to-peer electricity trading can enhance participation of prosumers which leads to better local demand/supply balancing and reduction of peak demand from the upstream grid.**

Keywords—electricity, peer-to-peer, power flow, distribution grid, renewable energy sources

I. INTRODUCTION

Peer-to-peer (P2P) electricity trading is a concept that allows local electricity trading (LET) between different peers (decentralized generation, prosumers, consumers) [1, 2] in a local distribution grid [3]. P2P electricity trading could contribute to increased power system stability, easier operation [4, 5], and it could allow active participation of households [6, 7]. Expected benefits include reduced peak demand and lower network losses [8]. On the other hand, many challenges still have to be solved to accelerate implementation of P2P electricity trading in practice and in a wider scope such as market design [1], congestion [9], and ICT solutions [10, 11]. P2P electricity trading can improve economic dispatch, unit commitment, voltage stability [12], congestion management [13] and Volt/VAr control. Additionally, grid codes [14], auxiliary services markets [15], control loops [16], and/or energy management systems [17] could also be used to regulate and control P2P trading.

In this paper the effects on power flows and local energy balance are analyzed in case where near-real-time P2P electricity trading is implemented. It is studied if a contribution to the reduction of peak load requirements and better local supply/demand balancing can be achieved based on a local market principle. Specifically, the impact of different producer's supply prices on the power flows in the grid is analyzed. The simulated P2P electricity trading is organized as an auction based local market in the distribution grid where supply and demand is aggregated. The result of the auctions is clearing price and quantities [18].

To conduct the research, scenario analysis of the impacts of different supply offering curves of participants is performed on the IEEE European LV Test Feeder [19]. In this IEEE distribution grid, a near-continuous LET is assumed based on the EUPHEMIA algorithm [20] with 5 min trading period for which we assumed that it behaves as a P2P market. In this way we can analyses the impact of P2P on power flows by analyzing a near-continuous double auction LET which simplifies the market modelling issues. For more on approach for calculation of equilibrium prices and volumes used here consult [18]. The applied method is briefly described in Section 2. The case study is described in Section 3, based on which the discussion is presented in Section 4.

II. SIMULATION METHOD FOR PEER-TO-PEER ELECTRICITY TRADING AND ESTIMATION OF IMPACTS ON THE GRID

To investigate the implications of different trading strategies and offering curves on power flows the P2P electricity trading is approximated with a near real-time double auction based local electricity market. Trading is done over 24 h with 5-minute trading intervals resulting in five-minute interval time series of equilibrium prices and volumes and five-minute unit commitment. This dispatch of committed peers is used as an input to the IEEE European LV Test Feeder [19, 21] to analyze the impact on power flows. The flowchart of the applied method and more detailed explanation is available in [18]. Firstly, peers create demand and supply offers, which are then sent to the double-auction market. There, offers are aggregated, and equilibrium volumes, prices are calculated, and least-cost dispatch is obtained and sent to the IEEE European LV Test Feeder grid, where impacts of electricity trading on power flows is analyzed. The simulation on IEEE European LV Test Feeder is conducted with one-second resolution using a five-minute dispatch from the previous step [18]. In order to get broader perspective, two scenarios of peer offering curves with different elasticities are used.

III. CASE STUDY

In this chapter the impact on power flow of different offering strategies is quantified. These offer curves strategies reflect moments of high electricity prices and scarcity of supply in one scenario and low electricity prices and oversupply in another scenario. The demand is defined by demand offering curve.

A. Scenarios and Input Data

The two producer's strategies by peers are: (S1) higher markup which means additional revenue on top of actual cost (S2) when they bid with the lower prices which are close to the short-run marginal costs (SRMC). Demand is defined by the demand curves and is the same for both scenarios. Generally, the demand is assumed inelastic in the point of

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demand and supply curves intersection (similar to real life electricity market [22, 23]).

Additionally, the reference scenario (SREF) is also created and in ordered to obtain comparative analysis. SREF assumes maximal production and inelastic demand. In this scenario feed-in tariffs for renewable energy sources and inelastic behavior of peers is assumed. The main features of scenarios are given in Table 1.

TABLE I. KEY DIFFERENCES OF THE ANALYZED SCENARIOS AND INPUT DATA FOR INDIVIDUAL PEERS.

Item \ Scenario	SREF	S1	S2
Maximal supply offering price	NA (feed-in-tariff)	High, 0.075 EUR/kWh	Low, 0.025 EUR/kWh
Price elasticity of demand	Perfectly inelastic (passive demand)	Elastic	Elastic

The consumption profiles are taken from the IEEE European LV Test Feeder [19]. In this analysis the 4 kW solar PV is added at every fourth peer. The applied approach resulted in total 14 solar PV system among 55 peers, as depicted in Fig. 1. The simulation is done in MATLAB [21].

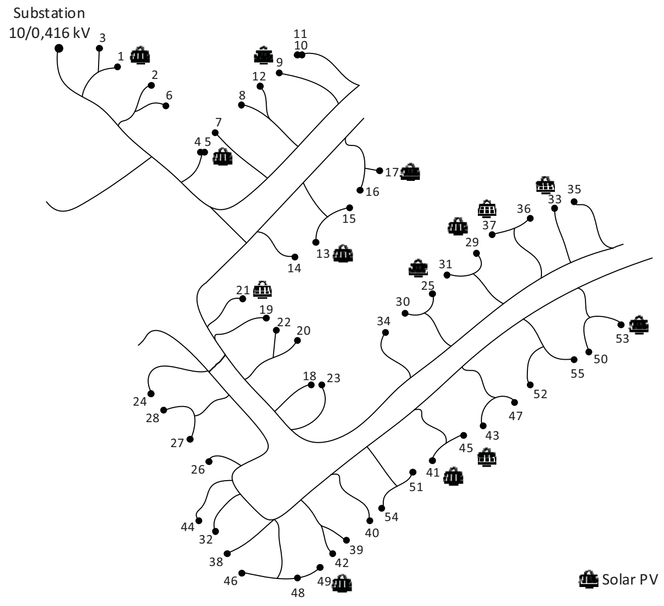


Fig. 1. The IEEE European LV Test Feeder used here

The PV production profiles are from [24] for June 1st. The analyzed is 8 a.m. to 10 a.m. when enough demand is available and PV production is also available. The minimum bidding steps are 0.5 kW [18]. The varying slopes of curves are shown in Fig. 2. The price of electricity used from the upstream grid is 0.100 EUR/kWh, and the price of selling to the upstream grid is 0.050 EUR/kWh. The aggregated supply and demand curves are shown in Fig. 3 for the time interval 9:35–9:40 a.m. for high and low-price scenarios.

B. *First Stage Outputs from the Simulation: Equilibrium Volumes and Prices*

In the first stage of approach prices, volumes, and least-cost dispatch calculation is calculated. The least cost dispatch is then input to the IEEE European LV Test Feeder. Then this feeder is analyzed for power flows. Figure 5(a) shows the total volumes in the LET and in Fig. 5(b) the market prices are shown for scenario S1 and S2.

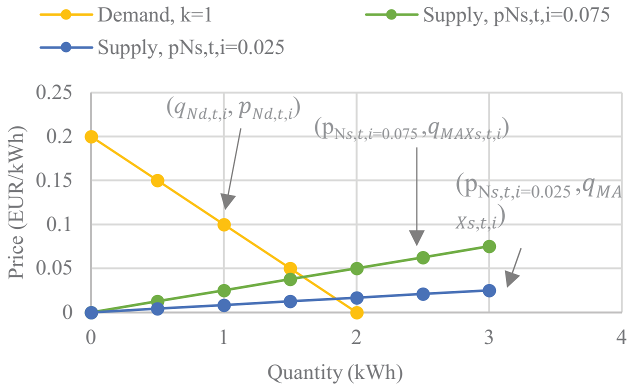


Fig. 2. Dmand and supply curves for the cases: (1) demand curves nominal price $p_{N\,d,t,i}$= 0.100 EUR/kWh, nominal demand $qD_{N\,t,i}$= 1 kWh and the slope of the curves is defined by the factor k; (2) supply curves maximal quantity $q_{MAX\,s,t,i}$= 3 kWh and the differences relate to the nominal supply price are defined by the nominal price $p_{N\,s,t,i}$.

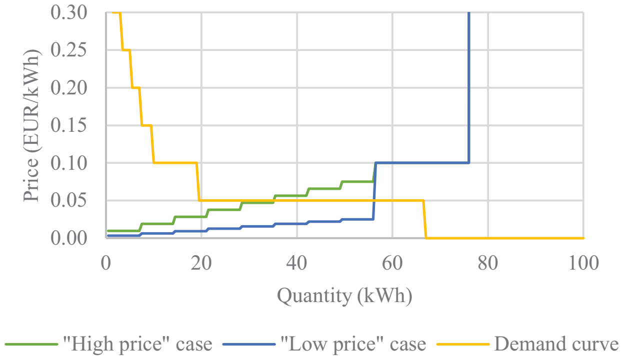


Fig. 3. Merit order supply and demand curves in the time interval 9:35 a.m. – 9:40 a.m.

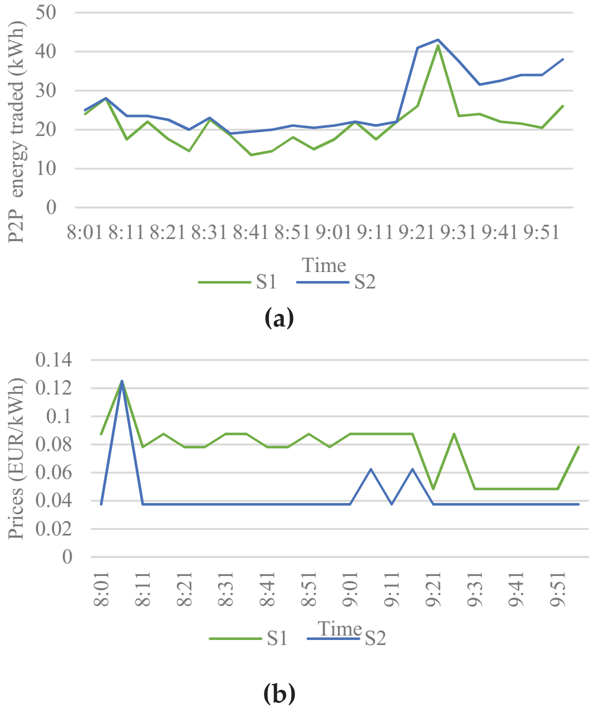


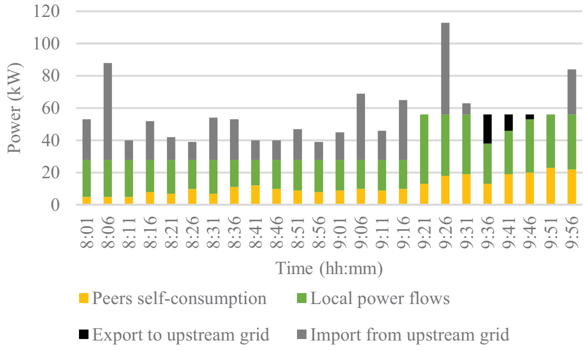
Fig. 4. Outputs of the market clearing: (a) market prices in analyzed time horizon, (b) volumes of P2P energy traded in analyzed time horizon.

C. *Results: Power flows*

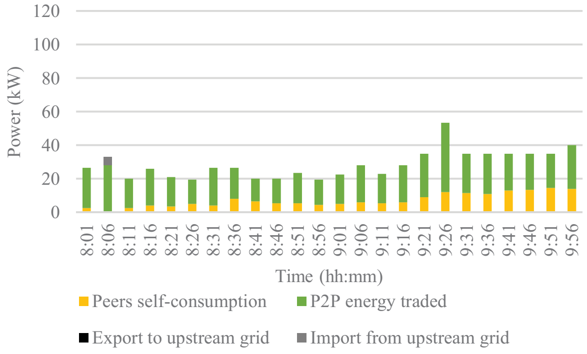
The impact of the P2P dispatch on demand/supply balance, import/export to upstream grid is shown in Fig. 5 for scenario SREF, S1 and S2. The energy balance in Fig. 5 is divided on: (1) Peers self-consumption, (2) traded P2P energy in the distribution grid which is the energy produced by the PV systems of the prosumers and not self-consumed but traded, (3) export to the upstream grid and (4) import from upstream grid.

Interesting insights are observed in reference scenario SREF (Fig. 5(a)). In this scenario the total consumption is at the maximal values. The total electricity production is also at maximal values but not enough to cover it by other production peers in the grid. Consequently, a significant share of energy is imported from the upstream network. Compared to the previous case the scenarios with implemented P2P trading (Fig. 5(b)-(c)) have lower total consumption due to introduction of price signals to consumers which is done by bidding the demand curves, which enables a decrease of consumption and avoidance of extreme market prices is possible depending on demand elasticity values and market prices (Fig. 2 and 3).

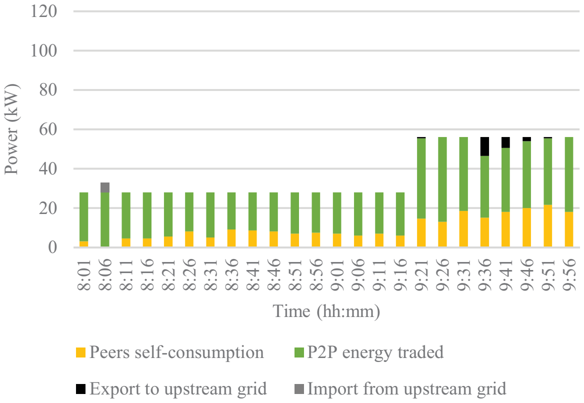
The Fig. 5(b) shows the power balance for the S1 scenario. This is the P2P electricity trading case with high producer markup (i.e. offer prices) and higher than average demand elasticity. This all resulted in decrease of total consumption and decrease in production compared to the SREF scenario. All combined, it resulted in decrease of imports from the upstream grid while exports to the upstream grid perished. On the other hand, in scenario S2 shown in Fig. 5(c) the lower producer markup (i.e. lower supply prices) resulted in the increased consumption and traded volumes in P2P market. Also, the exports to the upstream grid are observed in this scenario.



(a)



(b)



(c)

Fig. 5. Energy balance of the feeder: (a) Energy balance in reference scenario SREF; (b) Energy balance in the S1 scenario; (c) Energy balance in the S2 scenario.

In Fig. 6, the feeder self-sufficiency is shown, which is calculated as a share of total energy produced and total energy consumption of the feeder.

Fig. 6. Self-sufficiency of the prosumers located at the anlyzed distribution grid feeder.

The results in Fig. 6 clearly show that the P2P trading increases the self-sufficiency of the distribution grid, except in the times (around 9:41 am) when in the SREF scenario there are exports to the upstream grid. It can be pointed out that the implementation of P2P electricity trading nears the feeder self-sufficiency ratio towards 100%, subject to technical and economic constraints.

IV. DISCUSSION

The effects of different elasticities and prices in offering curves of the peers participating in the P2P electricity trading on power flows, self-sufficiency, consumption and production in the distribution grid were studied here. The results show that P2P electricity trading can contribute to the increase of local supply-demand balance, it can increase self-consumption rates and decrease imports from the upstream grid. The producer's strategies for supply curves have significant impacts on market-clearing prices and quantities, i.e., local consumption and production, and thus power flows. In the observed scenarios, the decrease supply prices resulted in the decrease of equilibrium prices and increase traded volumes. The results are valuable from the point of view of peers that can participate in the P2P electricity trading and from the point of view of policy makers and planners that will work on the design and implementation of markets for P2P electricity trading. Planned future work will be related to creation of demand and supply offer curves that will ensure optimal bidding based on the game theory [25, 26, 27]. Further, an implementation of P2P electricity trading is foreseen in the laboratory setup and in pilot-project in real-life distribution grid [5, 28] accounting for RoCoF issues in grids with high wind penetration levels [29].

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