Assessing the Impact of Peer-to-Peer Markets on Distribution Grid Operation

— Due to the considerable increase of distributed energy resources, a new model of energy trading called peer-to-peer (P2P) has emerged in local energy communities that play a key role in the proliferation of renewable energy sources. However, although local and distributed power trading allows for a more decentralized and open grid, these models have a significant impact on the control, operation, and planning of the electricity distribution grid. Thus, reducing the demand for power at an affordable price is one of the main objectives of P2P markets, considering the different voltage limits and possible congestion existing in the distribution system. Thus, the main goal of this work is to evaluate the impact of the P2P market on the distribution network operation. This work includes an energy community in a neighborhood involving nine connected houses and one school, involving different renewable technologies and energy storage systems installed in each consumer and/or prosumer. The simulation results indicate that in the presence of local distributed generation and the inclusion of energy storage devices and electric vehicles allow a high-cost reduction (16%) and a very positive impact on the distribution system in terms of congestion and voltage deviations.

I. Obejctive

The objective of this work is to evaluate the impact of the P2P market on the distribution network operation, considering the different voltage limits and possible congestion that exist in the distribution system. This work includes an energy community in a neighborhood involving nine connected houses and one school, involving different renewable technologies and energy storage systems installed in each consumer and/or prosumer. The simulation results indicate that in the presence of local distributed generation and the inclusion of energy storage devices and electric vehicles allow a high-cost reduction (16%) and a very positive impact on the distribution system in terms of congestion and voltage deviations.

II. Methodology

A. Sets/Indices

- \( t \in \Omega^T \) \( w \in \Omega^W \) \( c \in \Omega^C \) \( f \in \Omega^F \)

B. Parameters

- \( C_{E_{W,S}} \) Charging efficiency of the Prosumer w’s ESS
- \( C_{E_{W,V}} \) Charging efficiency of Prosumer w’s EV
- \( h_{W,L} \) Power at time \( t \) of phase \( f \) of appliance \( c \) of house \( w \)
- \( I_{L,W,L} \) Inflexible load of household \( w \) in period \( t \)
- \( N_{W,S,C} \) Number of controllable appliances \( c \) in phase \( f \) of house \( w \)
- \( P_{f,\text{base}} \) Baseline power of appliance \( c \) of house \( w \)

C. Variables

- \( P_\text{PV,prod} \) Available power of the PV system of house \( w \) in period \( t \) \( s \)
- \( P_\text{ESS,charged} \) Charging power of ESS of house \( w \)
- \( P_\text{ESS,discharged} \) Discharging power of ESS of house \( w \)
- \( P_\text{EV,charged} \) Charging power of EV of house \( w \)
- \( P_\text{EV,discharged} \) Discharging power of EV of house \( w \)
- \( S_{OC_{w}} \) Initial SOE of the ESS of house \( w \)
- \( S_{OC_{w,\text{max}}} \) Maximum SOE of the ESS of house \( w \)
- \( S_{OC_{w,\text{min}}} \) Minimum SOE of the ESS of house \( w \)
- \( T_{ev_{min}} \) Minimum SOE of the EV of house \( w \)
- \( T_{ev_{max}} \) Maximum SOE of the EV of house \( w \)
- \( T_{ev_{in}} \) Initial SOE of the EV of house \( w \)
- \( T_{ev_{min}} \) Minimum SOE of the EV of house \( w \)
- \( T_{ev_{max}} \) Maximum SOE of the EV of house \( w \)
- \( \delta_{\text{EV}} \) Discharging efficiency of the EV of house \( w \)
- \( \delta_{\text{ESS,use}} \) Discharging efficiency of the ESS of house \( w \)
- \( \delta_{\text{ESS,charged}} \) Charging efficiency of the ESS of house \( w \)
- \( \delta_{\text{EV,charged}} \) Charging efficiency of the EV of house \( w \)
- \( \delta_{\text{EV,discharged}} \) Discharging efficiency of the EV of house \( w \)
- \( \delta_{\text{ESS,use}} \) Discharging efficiency of the ESS of house \( w \)

Energy buying price [€/MWh]

Energy selling price [€/MWh]
B. Literature Review

The continuous integration of DER in the electricity grid requires the development of new management models to satisfy self-consumption in period \( t \) while in period \( t' \) used to satisfy self-consumption in period \( t \) with academia and industry worldwide. In [9], a model was developed where prosumers participate in demand response (DR) programs through variable tariff schemes. The results of these markets in the network.

C. Contributions and Manuscript Organization

- Present a solution for congestion control in a P2P distribution system operator provides information to peers to guide the interaction between the energy transaction operator and the network operator.
- Present a solution for congestion control in a P2P environment. A management method based on the environment called peer selection. In this solution, the distribution network. In [11] was presented a voltage fluctuation and power quality fluctuations, overloads, the distribution network may change such as voltage congestion and voltage deviations. This work introduces a stochastic optimization model which uses a set of appliances congestion control in a P2P environment.

The literature review shows several works that provide a good understanding of the current state of research in this area. However, most of these works do not consider the uncertainty of DERs. The work of [13] is particularly relevant as it presents a solution for congestion control in a P2P environment. This solution is based on the peer selection method, which is able to provide information to peers to guide the interaction between the energy transaction operator and the network operator. This work introduces a stochastic optimization model which uses a set of appliances to control congestion and voltage deviations. This method is able to handle the uncertainty of DERs and provides a good solution for congestion control in a P2P environment.

A. Background

The literature review shows several works that provide a good understanding of the current state of research in this area. However, most of these works do not consider the uncertainty of DERs. The work of [13] is particularly relevant as it presents a solution for congestion control in a P2P environment. This solution is based on the peer selection method, which is able to provide information to peers to guide the interaction between the energy transaction operator and the network operator. This work introduces a stochastic optimization model which uses a set of appliances to control congestion and voltage deviations. This method is able to handle the uncertainty of DERs and provides a good solution for congestion control in a P2P environment.
A. Objective Function

Prosumers Total Minimization Cost

\[
\begin{align*}
\text{Cost} & = \sum_{s} \rho_s \sum_{w} \sum_{t} (\lambda_{\text{pur},w,t} \cdot P_{\text{pur},w,t} \cdot \Delta T) - \sum_{w} \lambda_{\text{vend},w,t} \cdot P_{\text{vend},w,t} \cdot \Delta T
\end{align*}
\]

B. Constraints

\[
\begin{align*}
P_{\text{pur},w,t} & = P_{\text{grid},w,t} + P_{\text{local},w,t} \\
P_{\text{vend},w,t} & = P_{\text{grid},w,t} + P_{\text{local},w,t} \\
\sum_{w} P_{\text{comp,neighb}} & = \sum_{w} P_{\text{vend,neighb}} \\
P_{\text{pur},w,t} & = P_{\text{pur,grid},w,t} + P_{\text{pur,local},w,t} \\
P_{\text{vend},w,t} & = P_{\text{vend,grid},w,t} + P_{\text{vend,local},w,t} \\
0 & \leq P_{\text{EV,charge},w,t} \leq R_{\text{EV,charge},w,t} \\
w & \in \left[ T_{w}, T_{\text{d},w} \right] \\
0 & \leq P_{\text{EV,disch},w,t} \leq R_{\text{EV,disch},w,t} \cdot (1 - \chi_{\text{EV,charge},w,t}) \\
w & \in \left[ T_{\text{d},w}, T_{\text{d},w} \right] \\
\text{SOC}_{\text{EV,charge},w} & = \text{SOC}_{\text{EV,initial},w} + CE_{\text{EV,charge},w} \cdot P_{\text{EV,charge},w,t} \cdot \Delta T \\
& - p_{\text{EV,disch},w,t} \cdot \Delta T \\
& \forall w, t \in \left[ T_{\text{d},w} - T_{\text{d},w} \right] \\
\text{SOC}_{\text{EV,disch},w} & = \text{SOC}_{\text{EV,initial},w} + CE_{\text{EV,disch},w} \cdot P_{\text{EV,disch},w,t} \cdot \Delta T \\
& - p_{\text{EV,disch},w,t} \cdot \Delta T \\
& \forall w, t \in \left[ T_{\text{d},w} - T_{\text{d},w} \right] \\
\text{SOC}_{\text{EV,charge},w} & \leq \text{SOC}_{\text{EV,charge},w} \leq \text{SOC}_{\text{EV,disch},w} \leq \text{SOC}_{\text{EV,Charge,Max},w} \\
\text{SOC}_{\text{EV,disch},w} & = \text{SOC}_{\text{EV,Charge,Max},w} \forall w, t \in \left[ T_{\text{d},w} - T_{\text{d},w} \right]
\end{align*}
\]
\[
\begin{align*}
\sum_{w} p_{\text{in},w,t} & - \sum_{w} p_{\text{out},w,t} + \sum_{w} p_{\text{ESS,used}} + \sum_{w} p_{\text{HVAC,used}} \\
& + \sum_{w} p_{\text{in,Load,Load}} + \sum_{w} p_{\text{out,Load}} - \sum_{w} q_{\text{out,Load}} + \sum_{w} q_{\text{in,Load}} \\
& = \sum_{w} p_{\text{in,Load}} + \sum_{w} p_{\text{machine,Load}} + \sum_{w} p_{\text{charge,Load}} \\
& + \sum_{w} p_{\text{charge,Load}} + \frac{1}{2} \sum_{w} p_{\text{Load}} \\
& + \sum_{w} q_{\text{in,Load}} + \sum_{w} q_{\text{machine,Load}} + \sum_{w} q_{\text{charge,Load}} \\
& + \sum_{w} q_{\text{charge,Load}} + \frac{1}{2} \sum_{w} q_{\text{Load}} \\
& = \sum_{w} (\sum_{w} p_{\text{in,Load}} - \sum_{w} p_{\text{out,Load}} + \sum_{w} p_{\text{machine,Load}} + \sum_{w} p_{\text{charge,Load}}) \\
& + \sum_{w} (\sum_{w} q_{\text{in,Load}} + \sum_{w} q_{\text{machine,Load}} + \sum_{w} q_{\text{charge,Load}}) \\
& \text{subject to (33)}
\end{align*}
\]

In (30) and (31) represent the active and reactive losses in the system, more specifically PV. The inclusion of PV and all the energy needed to satisfy consumers is obtained only from consumers. In this case, the entire load is inflexible, fixed energy transaction fee between community members and discharge rate of 0.6 kW, and an efficiency of 90%. A community has a different load and DER profile to increase the community’s flexibility.

A. Data and Assumptions

In Case 2, local energy generation is introduced in the neighborhood forming an energetic community. This system has a nominal voltage of 12.66 kV. Each element of the energy community is considered. This system has a generation and the presence of ESSs and EVs greatly affect the system, more specifically PV. The inclusion of PV and all the energy needed to satisfy consumers is obtained only from consumers. In this case, the entire load is inflexible, fixed energy transaction fee between community members and discharge rate of 0.6 kW, and an efficiency of 90%. A community has a different load and DER profile to increase the community's flexibility.
B. Discussion of Numerical Results

In this section, the results are presented, and a discussion of these results follows. In the first case study (base), there is no energy generation or storage sources, there are only consumers. In this case, the entire load is inflexible, and all the energy needed to satisfy consumers is obtained through the electrical network. Each consumer's load profile is equal to the energy that is purchased from the grid.

In case 2, the generation of local energy in the system is added, more specifically the generation of photovoltaic energy. The sale of energy between prosumers (neighbourhood) is allowed. In Fig. 2, the costs associated with the purchase of energy were analysed. Case 1 (without generation) presents the highest total costs compared to Case 2. Comparing the cases, it can be seen a cost reduction from case 1 to case 2 of about 16%. This fact was due to the participation of users with generation systems and ESSs in Case 2, where stored energy from RES (PV) is cheaper than importing energy from the grid.

In case 2, the individual consumption of each network user comes from various energy sources. Thus, in Fig. 3 the aggregation of energy by sources of the total energy system is presented. From the figure, approximately 42% of the total load supply is achieved whenever possible by generation sources or storage sources ($PV_{ESS\_EV\_TOTAL}$). These home energy management systems are loaded during the period when energy is cheapest and off-loaded at the peak hour where the energy price is highest and provide users with greater energy flexibility compared to the base case where it is not.

Congestion in the power grid transmission lines is one of the biggest problems for most participants in energy markets. They limit electricity exchanges both with the grid and with the neighborhood, creating increased risks for market development.

Through the analysis of the results of the case studies, it is possible to verify a very significant improvement in the problem of grid congestion, with the inclusion of energy-producing participants. In Case 1, when there is no local generation by the houses, there are lines in which the line loading limit is exceeded, which will hinder the stability of the electricity transmission network and put at risk the energy transactions of market participants with the electricity network.

With the integration of participants in the energy market with energy generation (case 2) to be able to carry out P2P transactions, the congestion problems no longer exist. All lines of the electrical system are within the established limits as can be seen in Fig. 4.

One of the main objectives of an electrical system is to transmit electrical energy to maintain a grid frequency and voltage within limits around their nominal values. It is possible to see a significant difference in voltage deviations when comparing the two cases. In Case 2, the voltage deviations in all community nodes are smaller than in Case 1, as can be seen in Fig. 5. This is due to the integration of DERs, which leads to an improvement in the average voltage deviation by approximately 44.65%.
Creating more scenarios, namely with greater power work includes the expectation to expand the case study, in the stability conditions of the distribution network. Future with respect to overall costs, also leading to an improvement generation and storage devices can ensure an improvement markets due to their flexibility, the presence of local presence of storage devices. In general, the P2P energy did not occur when introducing local generation and in the aggregation of energy by type than in case 2, most favorable, showing voltage deviation improvements of approximately 42% of the total supply of the cargo in the numerical results of this study show that the P2P approach allows greater use of renewable energy based on the aggregation of energy by type than in case 2, and voltage diversion. To carry out the analysis, a MILP stochastic model was developed based on the transactive market can lead to a reduction in total system costs and efficient flexibility securing mechanism to support distribution network and its constraints. In this work, the participation of prosumers in DR was analyzed to increase network flexibility, reduce prosumer average voltage deviation

Figure 5. Average voltage deviations at network buses.

<table>
<thead>
<tr>
<th>Voltage Deviation</th>
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<tbody>
<tr>
<td>-0.5</td>
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<tr>
<td>-0.4</td>
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<tr>
<td>-0.3</td>
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<td>-0.2</td>
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<td>+0.4</td>
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References


