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

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***Abstract*—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.**

***Keywords-Energy community; Electricity distribution grid Energy trading; Peer-to-peer; Renewable energy sources.***

## I. NOMENCLATURE

### A. Sets/Indices

| | |
|---|---|
| $t \in \Omega^T$ | Time period. |
| $s \in \Omega^S$ | Scenarios. |
| $w \in \Omega^W$ | Prosumers $w = \{1, 2, 3\}$. |
| $c \in \Omega^C$ | Controllable appliances $c = \{HVAC, WM, DW\}$ |
| $f \in \Omega^F$ | Variable operation phases of controllable appliances. |

### B. Parameters

| | |
|---|---|
| $CE_{w,s}^{ESS}$ | Charging efficiency of the Prosumer w's ESS. |
| $CE_{w,s}^{EV}$ | Charging efficiency of the Prosumer w's EV. |
| $\eta_{w,t}^{ESS,disch}$ | Discharging efficiency of the ESS of prosumer $w$. |
| $\eta_{w,t}^{EV,disch}$ | Discharging efficiency of the EV of prosumer $w$. |
| $InfLoad_{w,t}$ | Inflexible load of household $w$ in period $t$ [kW]. |
| $N_{w,s,c}$, | Periods of operation for the controllable appliance $c$ of prosumer $w$. |
| $P_{w,f,c,s}^{fase}$ | Power consumed by controllable appliance $c$ of prosumer $w$ while in phase $f$ [kW]. |
| $P_{w,t,s}^{PV,prod}$ | Available power of the PV system of household $w$ in period t [kW]. |
| $R_{w,s}^{ESS,charg}$ | Charging rate of ESS of prosumer $w$ [kW]. |
| $R_{w,s}^{ESS,disch}$ | Discharging rate of ESS of prosumer $w$ [kW]. |
| $R_{w,s}^{EV,charg}$ | Charging rate of EV of prosumer $w$ [kW]. |
| $R_{w,s}^{EV,disch}$ | Discharging rate of EV of prosumer $w$ [kW]. |
| $SOC_{w,s}^{ESS,ini}$ | Initial SOE of the ESS of prosumer $w$ [kWh]. |
| $SOC_{w,s}^{ESS,max}$ | Maximum SOE of the ESS of prosumer $w$ [kWh]. |
| $SOC_{w}^{ESS,min}$ | Minimum SOE of the ESS of prosumer $w$ [kWh]. |
| $SOC_{w,s}^{EV,ini}$ | Initial SOE of the EV of prosumer $w$ [kWh]. |
| $SOC_{w,s}^{EV,max}$ | Maximum SOE of the EV of prosumer $w$ [kWh]. |
| $SOC_{w,s}^{EV,min}$ | Minimum SOE of the EV of prosumer $w$ [kWh]. |
| $T_{w,s}^{a}$ | Arrival time of the EV of prosumer $w$. |
| $T_{w,s}^{d}$ | Departure period of the EV of prosumer $w$. |
| $T_{w,f,c,s}^{dur}$ | Duration of phase $f$ of controllable appliance $c$ of prosumer $w$ [number of $\Delta T$-hour periods]. |
| $\lambda_{t,s}^{pur}$ | Energy buying price [€/MWh]. |
| $\lambda_{t,s}^{vend}$ | Energy selling price [€/MWh]. |
| $\Delta T$ | Time interval duration [t]. |

### C. Variables

| | |
|---|---|
| $P_{w,t,s}^{pur,grid}$ | Portion of total power procured from the grid by prosumer $w$ in period $t$ [kW]. |
| $P_{w,t,s}^{pur,local}$ | Portion of power procured from the local neighborhood by prosumer $w$ in period $t$ [kW]. |
| $P_{w,t,s}^{pur,T}$ | Total power procured by prosumer $w$ in period $t$ [kW]. |
| $P_{t,w,s}^{ESS,charge}$ | Charging power of ESS of prosumer $w$ in period $t$ [kW]. |
| $P_{w,t,s}^{ESS,disch}$ | Discharging power of ESS of prosumer $w$ in period $t$ [kW]. |
| $P_{w,t,s}^{ESS,used}$ | Portion of the ESS discharging power of prosumer $w$ used to satisfy self-consumption in period $t$ [kW]. |
| $P_{t,w,s}^{EV,charge}$ | Charging power of EV of prosumer $w$ in period $t$ [kW]. |
| $P_{w,t,s}^{EV,disch}$ | Discharging power of EV of prosumer $w$ in period $t$ [kW]. |

| | |
|---|---|
| $P_{w,t,s}^{EV,used}$ | Portion of the EV discharging power of prosumer $w$ used to satisfy self-consumption in period $t$ [kW]. |
| $P_{w,t',c,s}^{mach}$ | Power consumed by controllable appliance $c$ of prosumer $w$ while in period $t$ [kW]. |
| $P_{w,t,s}^{PV,used}$ | Portion of the PV power of prosumer $w$ used to satisfy self-consumption in period $t$ [kW]. |
| $P_{w,t,s}^{vend,ESS}$ | Portion of the ESS discharging power of prosumer $w$ sold to the grid or the neighbourhood in period $t$ [kW]. |
| $P_{w,t,s}^{vend,EV}$ | Portion of the EV discharging power of prosumer $w$ sold to the grid or the neighbourhood in period $t$ [kW] |
| $P_{w,t,s}^{vend,grid}$ | Portion of the power injected to grid by prosumer $w$ that flows back to the grid in period $t$ [kW]. |
| $P_{w,t,s}^{vend,local}$ | Portion of the power injected to grid by prosumer $w$ that is locally used in the neighborhood in period $t$ [kW]. |
| $P_{w,t,s}^{vend,PV}$ | Portion of the PV power of prosumer $w$ sold to the grid or to the neighbourhood in period $t$ [kW]. |
| $P_{w,h,s}^{vend,T}$ | Total power injected to grid prosumer $w$ in period $t$ [kW]. |
| $SOC_{t,w,s}^{ESS}$ | SOE of ESS from prosumer $w$ in period $t$ [kWh]. |
| $SOC_{t,w,s}^{EV}$ | SOE of EV from prosumer $w$ in period $t$ [kWh]. |
| $x_{w,s,t'}^{1}$ | Binary variable. 1 if the neighborhood is drawing power from the grid in period t; else 0 |
| $x_{w,s,t'}^{2}$ | Binary variable. 1 if the power flows from grid to prosumers/if EV is charging (w = {1, 2, 3}) for prosumer $w$ in period $t$; else 0. |
| $x_{w,s,t'}^{3}$ | Binary variable. 1 if the power flows from grid to prosumers/ if ESS is charging (w = {1, 2, 3}) for prosumer $w$ in period $t$; else 0. |
| $x_{w,s,t,f,c}^{fase}$ | Binary variables. 1 if phase $f$ of controllable appliance $c$ in prosumer $w$ is beginning/ongoing/finishing $(x = \{y, u, z\})$ in period $t$; else 0. |

## II. Introduction

### A. Background

In recent years, there has been a considerable growth of small-scale distributed energy resources (DERs), both at the business and residential levels. The way in which energy is produced and consumed is turning the traditional consumers into prosumers [1], i.e., they consume electricity but can also produce electricity.

Prosumers can play an important role in the distributed energy structure, as they produce renewable electricity, and they are also able to efficiently modulate their demand. The presence of home energy management systems (HEMS) in every home, together with energy storage devices (ESS), and electric vehicles (EV), will allow a good response to the demand in the electricity market [2] – [4].

The continuous integration of DER in the electricity grid requires the development of new management models to restructure and make the energy market more flexible.

Due to the characteristics (variability and uncertainty) of DER, it is necessary to create energy markets that support them. This new paradigm creates an opportunity to make the conventional energy market more decentralized.

Thus, peer-to-peer (P2P) energy markets arise, also called shared economies, which allows direct energy exchange between prosumers and consumers in a local grid system [5], [6]. With the progressive growth of prosumers in the electrical network and the consequent increase in electrical transactions in local communities, the stability of the distribution network may change such as voltage fluctuations and power quality fluctuations, overloads, voltage drops, and bottlenecks. [7].

### B. Literature Review

In [8], the key aspects, structure, social perspectives, and policies of P2P energy trading were analyzed. It presented P2P commerce as a promising solution for the future of energy markets with great potential of growing together 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 have shown that the participation of prosumers in the DR can increase the system's flexibility and reduce prosumers' costs, however, the work does not explore the inherent problems of these markets in the network.

In [10], the impact of the integration of PV systems in distribution networks is studied. A decentralized hierarchical voltage control method was proposed with the objective of minimize the risks to violate the restrictions of the distribution network. In [11] was presented a voltage control method in the distribution system considering the P2P environment. A management method based on the interaction between the energy transaction operator and the distribution system operator was proposed.

In [12], a methodology based on sensitivity analysis was proposed to assess the impact of P2P transactions on the network to guarantee an energy exchange without violating the network restrictions, however, the variability and uncertainty of DERs were not considered. In [13] was presented a solution for congestion control in a P2P environment called peer selection. In this solution, the network operator provides information to peers to guide the possible peers.

### C. Contributions and Manuscript Organization

None of the previous approaches have focused on the aspect of neighborhood energy transactions or considered the different sources of uncertainty and variability other than those associated with renewable energy sources, coupled with analysis of the effect on the grid in terms of congestion and voltage deviations. This work introduces a stochastic optimization model which uses a set of appliances and DERs owned by prosumers to determine the minimum operating cost of the grid.

The main contributions are as follows:

- A stochastic model where prosumers participate in DR actions through varying price tariff scheme and quantify the benefits of doing so in terms of added flexibility and cost reductions.

- Assess the impact of the P2P energy community markets on the operation of the distribution network in terms of voltage and grid congestion.

The rest of the manuscript is set up in the following manner: Section III contains the mathematical formulation of the model. Section IV contains the results obtained from the model as well as a discussion of these results. Conclusions drawn from these results are presented in Section V.

## III. Mathematical Formulation

### A. Objective Function

In this work, a stochastic mixed-integer linear programming (MILP) optimization model is developed. The uncertainty and variability associated with the various sources are considered in this work, such as PV production and the departure and arrival times of EVs and ESS. The problem presented in this paper is programmed using GAMS 24.1.2. The objective function consists of minimizing the total costs associated with each prosumer (1).

$$Prosumers\ Total\ Minimization\ Cost = \sum_s \boldsymbol{\rho}_s \sum_w \sum_t (\boldsymbol{\lambda}_{t,s}^{pur} \,.\, \boldsymbol{P}_{w,t,s}^{pur,T} \,.\, \Delta T - \boldsymbol{\lambda}_{t,s}^{vend} \,.\, \boldsymbol{P}_{w,t,s}^{vend,T} \,.\, \Delta T) \quad (1)$$

### B. Constraints

In (2)-(4) the restrictions related to energy transactions with the neighborhood or with the grid are presented. In (2) shows that the energy purchased by each prosumer $w$ comes from the grid or the neighborhood. In (3), the total energy sold by each prosumer $w$ is destined for the grid or the neighborhood. Neighborhood energy transactions are represented in (4), where the total energy purchased must equal the total energy sold.

$$P_{w,t,s}^{pur,T} = P_{w,t,s}^{comp,grid} + P_{w,t,s}^{comp,local} \quad (2)$$

$$P_{w,t,s}^{vend,T} = P_{w,t,s}^{vend,grid} + P_{w,t,s}^{vend,local} \quad (3)$$

$$\sum_w P_{w,t,s}^{comp,neighb} = \sum_w P_{w,t,s}^{vend,neighb} \quad (4)$$

In (5), the PV production generated by the prosumer $w$ can be used for self-consumption or sold to the grid.

$$P_{w,t,s}^{pur,T} = P_{w,t,s}^{pur,grid} + P_{w,t,s}^{pur,local} \quad (5)$$

In (6)-(8) the equations of energy transactions between the neighborhood and the grid are represented. In (7) and (8), a possible limit is inflicted on the total power acquired by the prosumers, where the parameter $N$ can impose limits on the amount of energy coming from the network as a complementary demand-response strategy.

$$P_{w,t,s}^{vend,T} = P_{w,t,s}^{vend,PV} + P_{w,t,s}^{vend,EV} + P_{w,t,s}^{vend,ESS} \quad (6)$$

$$P_{w,t,s}^{pur,T} \leq N \,.\, x_{w,t',s}^{2} \quad (7)$$

$$P_{w,t,s}^{pur,T} \leq N \,.\, (1 - x_{w,t',s}^{2}) \quad (8)$$

In (9), the power balance equation for each prosumer $w$ is represented.

$$P_{w,t,s}^{pur,T} + P_{w,t,s}^{PV,used} + P_{w,t,s}^{EV,used} + P_{w,t,s}^{ESS,used} = P^{InfLoad}{}_{w,t,s} + P_{w,t,s}^{EV,charge} + P_{w,t,s}^{ESS,charge} + \sum_c P_{w,t',c,s}^{machine} \quad (9)$$

In (10) and (11), the equations for the flexible appliances existing in each household in the neighborhood are represented, such as the dishwasher (WM) and the washing machine (DW). Flexible devices operate on pre-defined cycles, and therefore, both the duration of operation and the consumption of the operation during the phases are known. However, bearing in mind the presence of DR, the operation of these devices can be moved to periods with lower prices.

$$P_{w,t',c,s}^{machine} = \sum_f (x_{w,t,f,c,s}^{fase} \,.\, P_{w,f,c,s}^{fase}) \quad (10)$$

$$\sum_f x_{w,t,f,c,s}^{fase} \leq 1 \quad (11)$$

$$y_{w,t,f,c,s}^{fase} \leq 1 \quad (12)$$

$$y_{w,t,f,c,s}^{fase} = y_{w,f,c,s,(t+T_{w,f,c,s)'}^{dur}}^{fase} \quad (13)$$

$$y_{w,t,f,c,s}^{fase} - z_{w,t,f,c,s}^{fase} = x_{w,t,f,c,s}^{fase} - x_{w,f,c,s,(t-1)'}^{fase} \quad (14)$$

$$z_{w,t,f,c,s}^{fase} = y_{w,t',f+1,c,s}^{fase} \quad (15)$$

$$\sum_t y_{w,t,f,c,s}^{fase} = N_{w,c,s} \quad (16)$$

The following model for EVs is shown in (17)-(23). The EV discharge power used for self-consumption of each prosumer w together with what is sold to the neighborhood, or the network must be equal to the efficiency of the EV discharge power of the respective prosumer (17). The charge and discharge limits are represented in (18) and (19) and the EV charge state conditions are defined in (20)-(23).

$$P_{w,t,s}^{EV,used} + P_{w,t,s}^{vend,EV} = \eta_{w,s}^{EV,disch} \,.\, P_{w,t,s}^{EV,disch} \quad (17)$$

$$0 \leq P_{w,t,s}^{EV,charge} \leq R_{w,s}^{EV,charge} \,.\, x_{w,t'}^{3}, \quad w \in [T_{w,s}^{a}, T_{w,s}^{d}] \quad (18)$$

$$0 \leq P_{w,t,s}^{EV,disch} \leq R_{w,s}^{EV,disch} \,.\, (1 - x_{w,t'}^{3}), \quad w \in [T_{w,s}^{a}, T_{w,s}^{d}] \quad (19)$$

$$SOC_{t,w,s}^{EV} = SOC_{t,w,s}^{EV,ini} + CE_{w,s}^{EV} \,.\, P_{w,t,s}^{EV,charge} \,.\, \Delta T - P_{w,t,s}^{EV,disch} \,.\, \Delta T \quad \forall w, se\ t = T_{w,s}^{a} \quad (20)$$

$$SOC_{t,w,s}^{EV} = SOC_{t-1,w,s}^{EV,ini} + CE_{t,s}^{EV} \,.\, P_{w,t,s}^{EV,charge} \,.\, \Delta T - P_{w,t,s}^{EV,disch} \,.\, \Delta T \quad \forall w, t \in t = [T_{w,s}^{a} - T_{w,s}^{b}] \quad (21)$$

$$SOC_{w,s}^{EV,min} \leq SOC_{t,w,s}^{EV} \leq SOC_{w,s}^{EV,max} \quad (22)$$

$$SOC_{t,w,s}^{EV} = SOC_{w,s}^{EV,max} \quad \forall w, se\ t = \boldsymbol{T}_{w,s}^{d} \quad (23)$$

The ESS device is modeled in (24)-(29), and a formulation like the way the EVs were described is presented.

$$P_{w,t,s}^{ESS,used} + P_{w,t,s}^{vend,ESS} = \eta_{w,s}^{ESS,disch} . P_{w,t,s}^{ESS,disch} \quad (24)$$

$$0 \le P_{w,t,s}^{ESS,charge} \le R_{w,s}^{ESS,charge} . x_{w,s,t}^{4}, \quad \forall w,t \quad (25)$$

$$0 \le P_{w,t,s}^{ESS,disch} \le R_{w,s}^{ESS,disch} . (1 - x_{w,s,t}^{4}) \quad \forall w,t \quad (26)$$

$$SOC_{t,w,s}^{ESS} = SOC_{t-1,w,s}^{ESS} + CE_{t,s}^{ESS} + P_{w,t,s}^{ESS,charge} . \Delta T - P_{w,t,s}^{ESS,disch} . \Delta T \quad \forall w,t \ge 1 \quad (27)$$

$$SOC_{t,w,s}^{ESS} = SOC_{w,s}^{EV,ini} \ \forall w \ se \ t = 1 \quad (28)$$

$$SOC_{w,s}^{ESS,min} \le SOC_{t,w,s}^{ESS} \le SOC_{w,s}^{ESS,max} \quad \forall w,t \quad (29)$$

According to the scenarios foreseen, in (30)-(32) the simplified model for heating, ventilation, and air conditioning (HVAC) systems is defined, which is mainly aimed at temperature control.

$$\theta_{w,t+1} = \beta_{w,s} * \theta_{w,t,s} + (1 + \beta_{w,s}) * (\theta_{w,t,s}^{0} + COP_{w,s} * R_{w,s} * P_{w,t,s}^{HVAC}) \quad (30)$$

$$\theta_{w}^{min} \le \theta_{w,t+1} \le \theta_{w}^{max} \quad \forall w,t \quad (31)$$

$$0 \le P_{w,t}^{HVAC} \le P_{w,t}^{HVAC,max} \quad \forall w,t \quad (32)$$

The main technical constraints for the operation of the distribution system are represented in (33)-(38). The balance of active and reactive power flows is represented respectively by (33) and (34), where the input power flow must equal the output power flow of a bus.

$$\sum_{w} P_{w,t,s,k}^{pur,T} - \sum_{w} P_{w,t,s,k}^{vend,T} + \sum_{w} P_{w,t,s}^{PV,used} + \sum_{w} P_{w,t,s}^{EV,used} + \sum_{w} P_{w,t,s}^{ESS,used} + P_{w,t,s}^{HVAC,used} + \sum_{in,k} P_{w,s,t,k} - \sum_{out,k} P_{w,s,t,k} = \sum_{out,w} P^{InfLoad}{}_{w,t,s} \sum_{w} P_{w,t',c,s,i}^{machine} + \sum_{w} P_{w,t,s}^{EV,charge} + \sum_{w} P_{w,t,s}^{ESS,charge} + \sum_{in,k} \frac{1}{2} PL_{k,s,t,w} + \sum_{out,k} \frac{1}{2} PL_{k,s,t,w} \quad (33)$$

$$\sum_{w} Q_{w,t,s,k}^{pur,T} - \sum_{w} Q_{w,t,s,k}^{vend,T} + \sum_{w} Q_{w,t,s}^{PV,used} + \sum_{w} Q_{w,t,s}^{EV,used} + \sum_{w} Q_{w,t,s}^{ESS,used} + Q_{w,t,s}^{HVAC,used} + \sum_{in,k} Q_{w,s,t,k} - \sum_{out,k} Q_{w,s,t,k} = \sum_{out,w} Q^{InfLoad}{}_{w,t,s} \sum_{w} Q_{w,t',c,s,i}^{machine} + \sum_{w} Q_{w,t,s}^{EV,charge} + \sum_{w} Q_{w,t,s}^{ESS,charge} + \sum_{in,k} \frac{1}{2} QL_{k,s,t,w} + \sum_{out,k} \frac{1}{2} QL_{k,s,t,w} \quad (34)$$

The linearized equations of active and reactive energy flow are represented in (35) and (36) and follow the "Kirchhoff's voltage law".

$$|P_{k,s,t} - (V_{nom}(\Delta V_{i,s,t} - \Delta V_{j,s,t}) g_k - V_{nom}^2 \, b_k \, \theta_{k,s,t})| \le MP_k(1 - u_{k,t}) \quad (35)$$

$$|Q_{k,s,t} - (-V_{nom}(\Delta V_{i,s,t} - \Delta V_{j,s,t}) b_k - V_{nom}^2 \, g_k \, \theta_{k,s,t})| \le MQ_k(1 - u_{k,t}) \quad (36)$$

$$\Delta V^{min} \le \Delta V_{i,s,t} \le \Delta V^{max} \quad (37)$$

$$\theta_{k,s,t} = \theta_{i,s,t} - \theta_{j,s,t} \quad (38)$$

The power flow limits in each line are shown in (39), where the maximum flow transfer capacity in each line is determined.

In (40) and (41) represent the active and reactive losses of each feeder, respectively.

$$P_{k,s,t}^2 + Q_{k,s,t}^2 \le (S_k^{max})^2 \quad (39)$$

$$PL_{k,s,t} = \frac{R_k(P_{k,s,t}^2 + Q_{k,s,t}^2)}{V_{nom}^2} \quad (40)$$

$$QL_{k,s,t} = \frac{x_k(P_{k,s,t}^2 + Q_{k,s,t}^2)}{V_{nom}^2} \quad (41)$$

## IV. RESULTS AND DISCUSSION

### A. Data and Assumptions

To validate the presented methodology, the test system of an energy community is considered. This system has a nominal voltage of 12.66 kV. Each element of the energy community has a different load and DER profile to increase the opportunity for energy transactions within it.

The system considered can be seen in Fig. 1, and it consists of nine houses and a school linked together (neighborhood) forming an energetic community.

All data and results presented are based on 24-hour periods on a typical weekday. The allocation of these DERs can be seen in Fig. 1 and their characteristics are provided in [9]

PV systems have a capacity of 1 kW each. The ESS has a capacity of 3 kWh, a maximum charge and discharge rate of 0.6 kW, with an initial state of charge (SOC) of 80%, a minimum SOC of 40%, and a charge and discharge efficiency of 90%.

The EVs have a capacity of 4 kWh, a maximum charge and discharge rate of 0.6 kW, and an efficiency of 90%. A fixed energy transaction fee between community members is 0.03 €/kWh [9].

In this work, it is assumed that the price of electricity follows the same trend as demand. Voltage deviations must be between 5% and -5% of the nominal voltage and at node 1, the voltage magnitude is set to $V_{nom}$ and its angle to 0.

In this work, two case studies are considered. In Case 1 (base case), there are no RESs 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.

In Case 2, local energy generation is introduced in the system, more specifically PV. The inclusion of PV generation and the presence of ESSs and EVs greatly influence the satisfaction of the response to the demand for energy, based on the production profile and general consumption of the system.

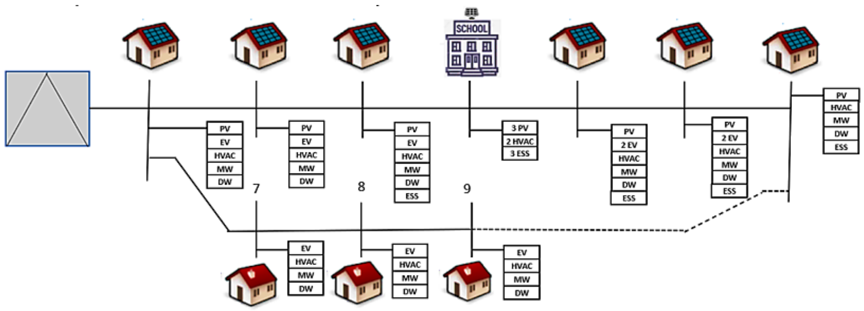


Figure 1. Schematic diagram of the case study.

*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. there was power generation.

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 %.

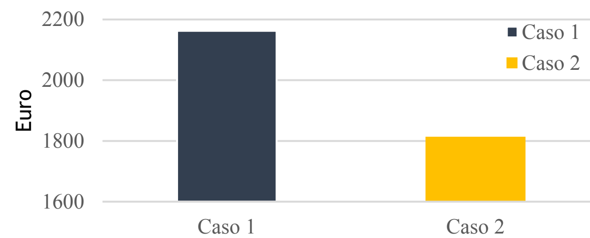


Figure 2. Total cost associated for each case.

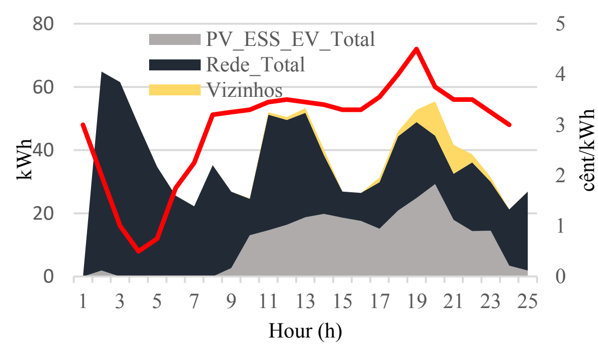


Figure 3. Energy aggregation per source type, Case2.

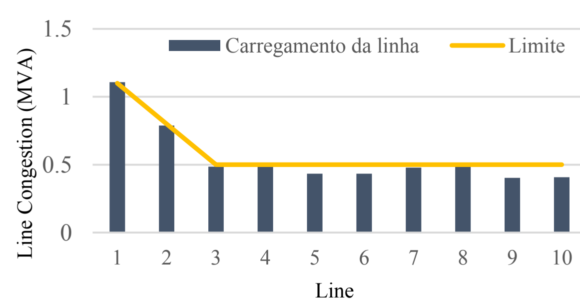


Figure 4. Line Congestion, Case2.

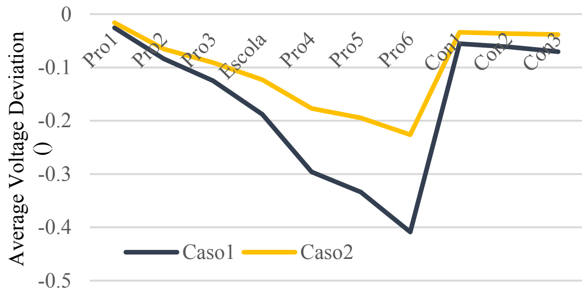

Figure 5. Average voltage deviations at network buses.

## V. Conclusion

In this work, the participation of prosumers in DR was analyzed to increase network flexibility, reduce prosumer costs, assess DER integration, and assess the impact of prosumers as an energy community have on the operation of the distribution system, especially in terms of congestion and voltage diversion. To carry out the analysis, a MILP stochastic model was developed based on the transactive energy trade between prosumers, while considering the network and its constraints.

The numerical results of this study show that the P2P market can lead to a reduction in total system costs and allow greater flexibility for system operation. Regarding the total associated costs, case 2 presents a cost reduction of about 16% compared to case 1. It was also verified that this approach allows greater use of renewable energy based on the aggregation of energy by type than in case 2, approximately 42% of the total supply of the cargo in conjunction with all DERs. Regarding the impact of P2P energy markets on the operation of the distribution network, through the simulation and the results obtained in this paper, case 2 is more favorable in terms of congestion and voltage deviations. The voltage deviations obtained in case 2 are the most favorable, showing voltage deviation improvements of up to 45%. Also, the congestions on certain lines in case 1 did not occur when introducing local generation and in the presence of storage devices. In general, the P2P energy markets due to their flexibility, the presence of local generation and storage devices can ensure an improvement with respect to overall costs, also leading to an improvement in the stability conditions of the distribution network. Future work includes the expectation to expand the case study, creating more scenarios, namely with greater power injection by the prosumers, and conducting a sensitivity analysis to the existence of overvoltages.

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