PhD Open Days

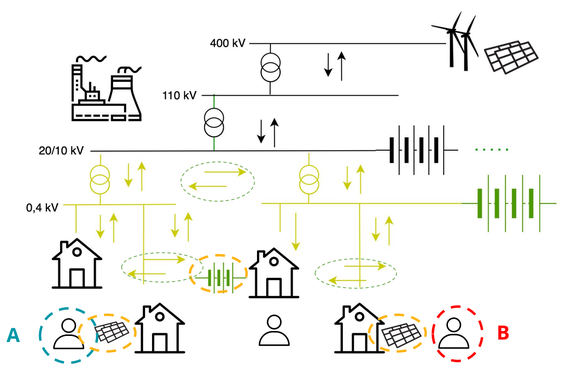
Peer-to-Peer (P2P) Electricity Markets for Low Voltage Networks

ENGINEERING AND PUBLIC POLICY (EPP)

DIANA VIEIRA FERNANDES (diana.vieira.fernandes@tecnico.ulisboa.pt)

I. Background

- ❏ Users can be producers and consumers (prosumers)
- ❏ Distributed unused capacity, mostly Renewable Energy Sources (RES)
- ❏ Focus is downstream (low voltage) with bidirectional flows



Sets of challenges:

Market:

- How to use available power capacity closer to consumption?
- How to set up (facilitate) markets

Network constraints

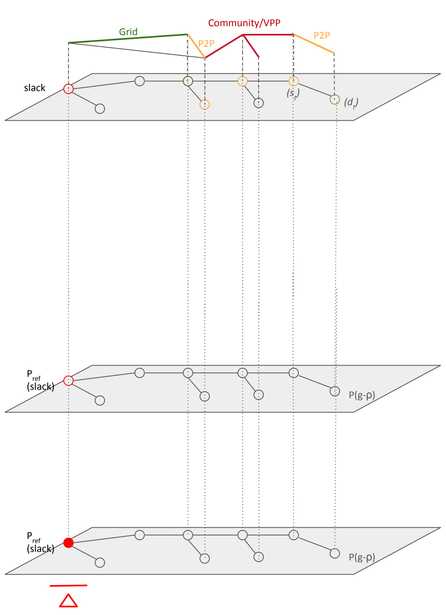
- physical limitations of the grid when used by multiple parties (shared resource)
- active participation of end users (can inject and receive electricity (not just receptor) across the grid (not just close microgrid structure)

II. Contributions

- ❏ Formalize and develop a novel model for a peer-to-peer clearance and settlement problem designed for integrating peer-to-peer energy trading in low-voltage, incorporating network constraints with multiple and concurrent autonomous users and different time windows;
- ❏ Fills a research gap by integrating distributed power generation of small, heterogeneous, and autonomous agents within Peer-to-Peer (P2P) trading mechanisms;
- ❏ Facilitates the execution of viable P2P energy exchanges, alongside traditional electricity retailers, merging these resources with existing market and operations mechanisms, in an open manner, with multiple users and transactions;
- ❏ Power flow equations are explicitly integrated where network topology is considered (to reflect the network state from several concurrent transactions);
- ❏ Allows clearance and integration with existing market structures and outputs a pre-operational dispatch schedule (assuming a centralized DSO that receives all potential trades from independent participants).

III. Model and Mathematical Formulation

Maximize the total quantity across all trades



transactive layer

physical layer

(system balance)

Objective Function

$$\underset{x_t, q_t, P_{ref}}{\text{maximize}} \quad \sum_{t \in T} x_t \cdot q_t$$

s.t.

Execution of Trades

$$\forall t \in T : 0 \leq x_t \leq 1$$

Load and Generation Adjustments Due to Trades

$$\forall i \in N \setminus \{i_{ref}\}, \forall t \in T :$$
$$g_i = g_i^0 + \sum_{t \in T} x_t q_t \mathbf{1}_{\{s_t = i\}},$$
$$\rho_i = \rho_i^0 + \sum_{t \in T} x_t q_t \mathbf{1}_{\{d_t = i\}},$$

Generation and load bounds

$$\underline{g}_i \leq g_i \leq \overline{g}_i,$$
$$\underline{\rho}_i \leq \rho_i \leq \overline{\rho}_i,$$

Nodal Power Balance

$$g_i - \rho_i = \sum_{j \in Adj(i)} B_{ij}(\theta_i - \theta_j),$$

Line Capacity Constraints

$$\forall i, j \in N :$$
$$|B_{ij}(\theta_i - \theta_j)| \leq \overline{P}_{ij},$$

Voltage Angle Differences

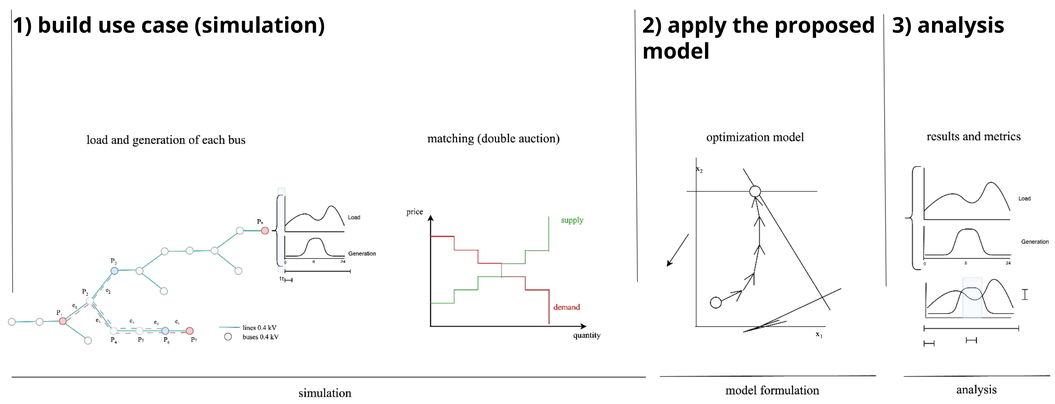
$$|\theta_i - \theta_j| \leq \frac{\pi}{6},$$
$$\theta_{i_{ref}} = 0,$$

Slack Power Mismatch

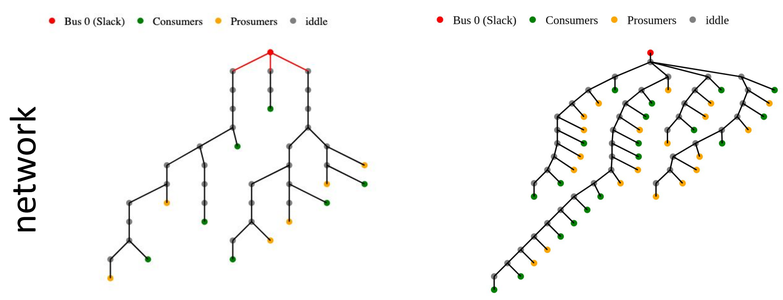
$$P_{i_{ref}} = \sum_{i \in N \setminus \{i_{ref}\}} (g_i - \rho_i),$$
$$|P_{i_{ref}}| \leq P^{\text{ref max}}$$

A P2P trade $t \in T$ is represented as $t = (s_t, d_t, q_t)$ where s_t is the source, d_t the destination, q_t the quantity of trade t. N is the set of all buses i in the system, and T be the set of all proposed peer-to-peer (P2P) trades in the network.

IV. Methods - System Setup



V. Implementation



Adapted CIGRE low voltage radial distribution network (44 bus system) with users' profile

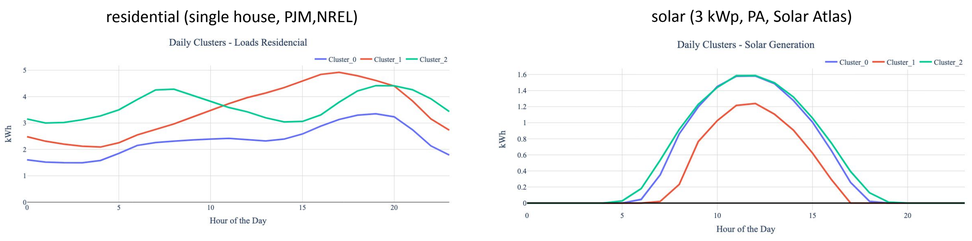
Adapted Synthetic Voltage Control LV Networks "Village" (80 bus system) with users' profile

Power Flow with trading (i.e. adding generation), connected to the external grid

50% of overall consumers (loads) are associated with local solar generation on the same bus.

generation and loads

Hourly time series, using K-means clustering (hourly) to get profiles for each bus.

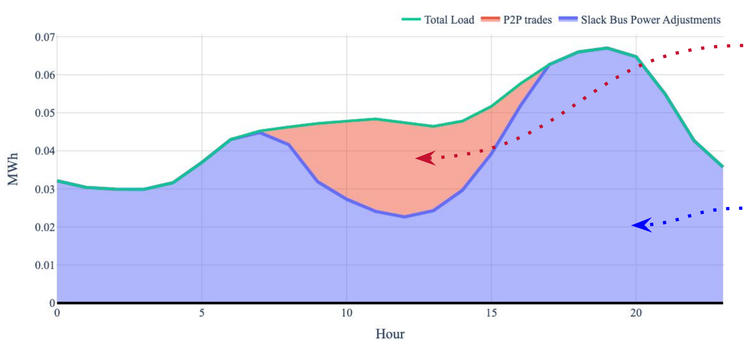


demand (load profiles)

supply (local generation profiles)

VI. Results

Total P2P traded and slack adjustments per hour - 80 bus system



integration/use of P2P (close unused capacity) total dispatched by P2P (i.e. < than demand (solar)

total power imported and exported through $\mathbf{P_{ref}}$ **(slack)** (or collectively, the "Grid") to meet demand of all buses within sub system/feeder

- ❏ The quantity available for trade is determined by the output of the generators (or sellers), specifically those using solar generation;
- ❏ This forward-looking approach not only maximizes unused local capacity (from P2P) but also ensures that the electrical system remains stable and within its operational boundaries;
- ❏ The model is designed to secure the fulfillment of non-dispatchable loads, effectively merging these resources with existing market mechanisms, in a decentralized and open manner, with multiple users.

VII. Paper and acknowledgments

Diana Vieira Fernandes, Nicolas Christin, Soummya Kar, Peer-to-Peer (P2P) Electricity Markets for Low Voltage Networks. To appear in IEEE SmartGridComm'24 - 2024 IEEE International Conference on Communications, Control, and Computing Technologies for Smart Grids (SmartGridComm). Pre-print (arXiv): https://arxiv.org/abs/2407.21403

This work is co-financed by Fundação para a Ciência e a Tecnologia (Portuguese Foundation for Science and Technology) through the Carnegie Mellon Portugal Program and under FCT grant UIDB/50009/2020-FCT.

Advisors:
Carlos Augusto Santos Silva (IST/UL),
Nicolas Christin (EPP and S3D/SCS CMU),
Soummya Kar (ECE CMU)

Engineering and Public Policy (IST & CMU)

phdopendays.tecnico.ulisboa.pt