Unified Decision-Making Framework in LV Distribution Systems: Combining Short-Term Operations and Long-Term Planning

Maurizio Vassallo, University of Liège, Belgium
Supervisor: Damien Ernst, University of Liège, Belgium

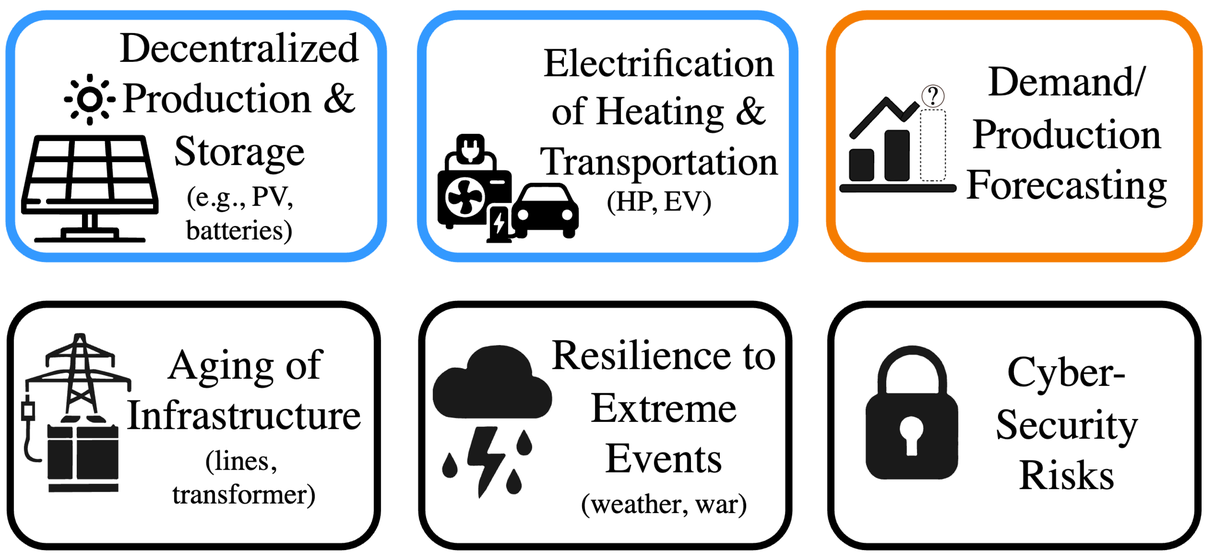
Introduction

Low-voltage (**LV**) distribution systems are becoming increasingly complex due to the greater integration of distributed energy resources (**DERs**) such as photovoltaic panels (**PVs**) and electric vehicles (**EVs**), batteries and heat pumps (**HPs**).

Short-term operations, such as PV curtailment, address immediate grid issues but are often separate from infrastructure **long-term planning**, such as transformer upgrades.

This separation results in inefficient investments and missed chances to use DER flexibility for sustainable grid modernization.

Challenges



Research question

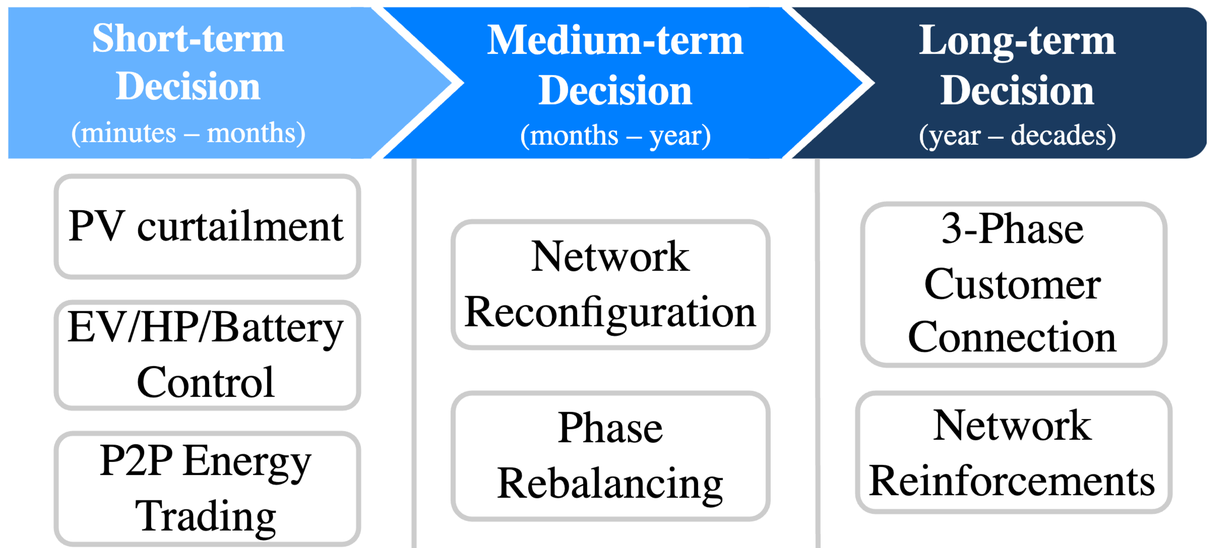
How can a unified decision-making framework effectively combine **short-term control strategies** and **long-term investment planning** to ensure cost-effective and robust network stability for LV networks under high DER penetration?

Contributions

- Develop a **unified decision-making framework** that integrates short-term operational control strategies with long-term infrastructure investment planning.
- Identify specific conditions under which **short-term** control solutions can offset **long-term** physical network upgrades.
- Propose a robustness analysis framework with a **no-regret policy** to ensure network decisions remain effective despite uncertainties in DER adoption and demand patterns.

Decision Categories

Our unified framework addresses decisions with time horizons to ensure immediate grid stability and long-term network evolution.



Problem Statement

$$\min_{B} \quad \sum_{t=1}^{T} \gamma^t \sum_{k \in \mathcal{K}} c_k \cdot B_{t,k} \tag{1}$$

$$\text{s.t.} \quad V^{min} \leq V_{i,t} \leq V^{max} \qquad \forall i \in \mathcal{N}, \forall t \in \mathcal{T} \tag{2}$$

$$|I_{ij,t}| \leq I_{ij}^{max} \qquad \forall (i,j) \in \mathcal{L}, \forall t \in \mathcal{T} \tag{3}$$

$$P_{i,t}^{curt} \leq P_{i,t} \qquad \forall i \in \mathcal{D}, \forall t \in \mathcal{T} \tag{4}$$

$$\sum_{k \in \mathcal{K}} c_k \cdot B_{t,k} \leq \text{Budget}_t \qquad \forall t \in \mathcal{T} \tag{5}$$

$$B_{t,k} \in \{0,1\} \qquad \forall k \in \mathcal{K}, \forall t \in \mathcal{T} \tag{6}$$

- $\mathcal{K}$ is the set of all available decisions
- $B_{t,k}$ represents the decision variable for option k at time period t
- c_k is the cost associated with decision k
- γ depends on both the discount and the inflation rate
- $V_{i,t}$ and $I_{ij,t}$ represent nodal voltages and branch currents
- $P_{i,t}^{curt}$ is the curtailed power from DERs
- $\mathcal{N}$, $\mathcal{L}$, $\mathcal{D}$ are the sets of nodes, lines, and DERs

Progress

[1] *Fair Voltage Control*: Developed an approach for PV inverter voltage control that achieves fair curtailment among prosumers

[2] *GIS-Based Network Topology Identification*: Developed an optimization methodology that reconstructs electrical network topologies using only geographical information system data

[3] *Phase Reconfiguration Optimization*: Designed a computationally efficient algorithm to optimize customer phase connections in networks with high DER penetration

Conclusion

- This research bridges the critical gap between **short-term** operational controls and **long-term** infrastructure investments through a novel **unified framework**.
- By making optimal decisions, our framework is expected to lead to **reductions in network costs** and **improved performance** compared to traditional, decoupled approaches.
- This work represents a step towards building more efficient, cost-effective, and **robust** LV power distribution networks in the age of decentralized energy.

References

[1] Maurizio Vassallo et al. "Fair Reinforcement Learning Algorithm for PV Active Control in LV Distribution Networks". In: *2023 International Conference on Clean Electrical Power (ICCEP)*. IEEE, June 2023, pp. 796–802.

[2] Maurizio Vassallo et al. "A Systematic Procedure for Topological Path Identification with Raw Data Transformation in Electrical Distribution Networks". In: *2024 7th International Conference on Energy, Electrical and Power Engineering (CEEPE)*. 2024, pp. 707–715.

[3] Maurizio Vassallo et al. "Phase Reconfiguration for Power Distribution Networks with High DERs Penetration". Powertech 2025 (preprint). 2025.