INTEGRATED PLANNING OF V2G-ENABLED CHARGING INFRASTRUCTURE AND DISTRIBUTION GRID OPERATION IN POSITIVE ENERGY DISTRICTS – INSIGHTS FROM THE V2G-QUESTS PROJECT

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Overview

The decarbonization of urban energy systems requires a coordinated transformation of electricity supply, distribution grids, and mobility systems. In particular, the increasing penetration of electric vehicles (EVs) poses significant challenges for distribution networks, while simultaneously offering flexibility potential through smart charging and Vehicle-to-Grid (V2G) operation. The ability of EVs to provide grid services has been discussed for nearly two decades, most prominently by Kempton and Tomić, who demonstrated the technical feasibility and system value of V2G-enabled vehicles for power system support [1].

At the same time, the integration of high shares of renewable energy sources at the distribution level intensifies voltage and congestion issues, requiring grid-aware operational strategies and advanced optimization approaches [2]. In this context, Positive Energy Districts (PEDs) have emerged as a key concept within European energy policy, aiming to achieve net-zero or net-positive energy balances at the district scale through the integrated design of buildings, local generation, flexibility, and mobility systems [3].

This work contributes by developing and applying optimization-based methods developed within the European research project *V2G-QUESTS* (Vehicle-to-Grid for Equitable Zero-Emission Transitions in Urban Districts). A particular focus is placed on urban districts with heterogeneous socio-economic characteristics, where mobility behavior, EV adoption, and grid conditions differ substantially.

Within V2G-QUESTS, the presented work contributes to the technical core of the project by developing algorithms that jointly address charging infrastructure planning and distribution grid operation. By embedding V2G-enabled EVs into a cost-minimized Optimal Power Flow (OPF) framework, the approach directly links mobility behavior and future share of EVs (coming from a simulation framework developed within the project) with distribution system constraints and operational flexibility, which is widely recognized as a key challenge for future power systems with high shares of distributed energy resources [4].

Methodology

The proposed framework combines charging infrastructure planning with a cost-minimized OPF formulation for medium-voltage distribution grids. Charging station deployment and grid operation are optimized simultaneously to ensure consistency between mobility demand, infrastructure investment, and network constraints.

Charging Infrastructure Planning

Charging infrastructure placement is formulated as an optimization problem that allocates installed charging capacity across grid nodes based on spatial demand patterns, expected EV availability, and grid hosting capacity. Investment decisions are represented by continuous variables and associated

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cost parameters, allowing the model to endogenously determine the amount and location of charging infrastructure while respecting regulatory and technical limits.

Optimal Power Flow Formulation

The OPF model represents the operational core of the framework. It captures renewable generation, stationary storage systems, EV charging and bidirectional V2G discharging, and power flows in the distribution grid. Both a linear DC-OPF approximation and a second-order cone programming (SOCP) relaxation of AC power flow are supported, enabling a trade-off between computational efficiency and physical accuracy.

The entire framework is implemented in Python using the Pyomo optimization environment and designed in a modular and extensible architecture to support scenario analysis and future model extensions.

Results and Case Study Application

The framework is parameterized for the three V2G-QUESTS case study districts (Aradas, Kanaleneiland, and Annelinn), which differ in spatial structure, socio-economic characteristics, and distribution grid topology. Functional verification is demonstrated using a detailed test system for the Annelinn district under a future scenario with high renewable penetration and electric mobility uptake. A snapshot of the grid utilization and active power-flow of each line is shown in Figure 1.

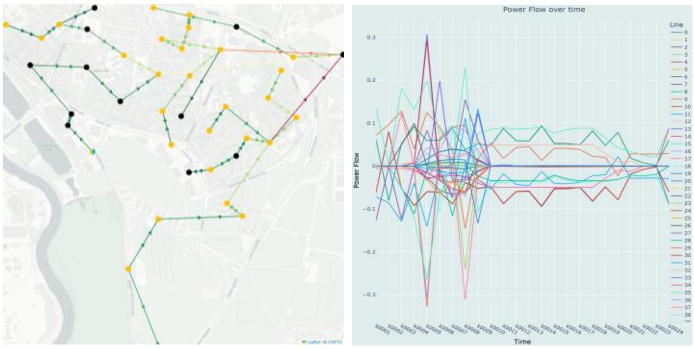

Figure 1: Grid utilization and renewable production at a given time t (left) and active power-flow of each line over the modeling horizon (right).

Simulation results indicate that coordinated smart charging and V2G operation can reduce electricity import costs by shifting charging demand and enabling discharging during high-price periods. Furthermore, V2G contributes to mitigating voltage violations during times of high renewable generation and reduces thermal loading of distribution lines. The charging infrastructure optimization distributes installed charging capacity in line with localized demand while respecting grid constraints, highlighting the importance of joint planning.

Overall, the results demonstrate that integrating charging infrastructure planning with distribution grid optimization is essential for realizing the flexibility potential of V2G in PEDs.

Referenzen

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