COORDINATED FLEXIBILITY MANAGEMENT OF HEAT PUMPS AND ELECTRIC VEHICLES: A DATA-DRIVEN APPROACH TO GRID STABILITY

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The increasing electrification of private households through electric vehicles and heat pumps imposes significant operational challenges on distribution grids. Previous work has demonstrated that decentralized flexibility, when coordinated by a central coordination function (COF), can effectively mitigate overload situations and support grid stability. The COF concept, introduced in a functional architecture for holistic grid- and market-oriented energy management, defines a multi-stage intervention hierarchy ranging from free consumer behavior and price-based incentives to active schedule control, situational adjustments, and emergency interventions during red-phase grid conditions [1]. Building on this framework, subsequent research evaluated allocation algorithms for EV charging using queue-based, slice-based, and fairness-oriented scheduling principles, including Hilbert-curve-based analysis to select efficient allocation strategies under different grid load characteristics [2]. More recently, the generation of synthetic datasets has been explored to assess COF behavior under long-term dynamic growth, especially with increasing shares of electric vehicles and heterogeneous user behavior patterns [3].

This work extends the COF principle to heat pumps as controllable thermal loads. Heat pumps represent a distinct category of flexibility: unlike EVs, which require discrete energy quantities within user-defined deadlines, heat pumps operate continuously with thermal inertia, allowing the COF to shift consumption through pre-heating, temporary throttling, or coordinated cycling. Integrating heat pumps into the COF therefore requires both a refined load-forecasting method and an expanded flexibility model. The existing COF architecture already provides the necessary components, load forecasting, expectation calculation, scheduling, real-time monitoring, and continuous self-optimization, to incorporate these new thermal flexibilities in parallel with EV charging control [1].

To evaluate the extended COF, a synthetic dataset is generated that includes both EV charging behavior and heat-pump operation. Following the dynamic dataset generation approach presented in prior work, household demand is modeled using stochastic user-behavior parameters such as synchronicity, continuity, cost affinity, and growth rates. The EV component follows established mobility and charging models, including probabilistic arrival and departure times, battery capacities, and daily driving distances. Heat pumps are modeled through COP-dependent thermal demand profiles, outdoor-temperature correlations, and user comfort constraints. As in earlier research, the synthetic dataset increases the share of flexible loads over time and introduces region-dependent behavioral variability to challenge the adaptability of the COF [3].

A real dataset e.g., multi-year transformer-level household load measurements is then used to calibrate and validate the synthetic data. This alignment ensures that baseline household consumption, temporal variability, and peak characteristics match real distribution-grid conditions. Using both datasets, COF simulations assess how heat-pump integration affects grid-load profiles, the frequency and severity of predicted congestion events, and the effectiveness of allocation strategies originally developed for EVs. The results demonstrate that thermal flexibility from heat pumps significantly increases the COF's ability to prevent overloads during winter periods, where EV charging and heating loads coincide. Moreover,

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combining heat-pump flexibility with optimized scheduling algorithms reduces maximum shifted work and improves fairness across households.

Overall, this work shows that extending the coordination function to heat pumps provides substantial additional flexibility, enhances grid stability in critical seasonal periods.

Referenzen

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