Trading in residential energy systems with storage: a kinetic mean-field approach

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We study a stochastic optimal control problem motivated by the operation of a large ensemble of residential storage devices coordinated by an energy aggregator. The aggregator remunerates prosumers in exchange for direct control of their batteries and seeks to jointly (i) reduce local supply-demand imbalances and (ii) exploit intraday price fluctuations through energy arbitrage. The core modeling feature is a kinetic mean-field formulation: the state of charge is treated as a position, the charging/discharging power as a velocity, and the control as an acceleration, thus encoding ramp-rate limitations and producing smooth power trajectories. This leads to a controlled McKean-Vlasov Langevin-type system in which both the drift and the objective functional depend on the time-marginal law of the state, allowing one to capture endogenous interaction effects and population-level stabilization incentives. The performance criterion combines the cost of grid exchange with convex penalties representing degradation and control effort, and includes mean-field terms that promote alignment with the population average; terminal contributions account for residual energy value and end-of-horizon coordination. The resulting control problem is Markovian and hypoelliptic, and naturally connects mean-field control with ultraparabolic operators of kinetic type. This viewpoint provides a coherent bridge between physically constrained storage actuation and law-dependent incentives in large-scale energy management. Numerical experiments based on deep learning solvers are presented to validate the model. From a computational standpoint, the problem is particularly challenging, as it yields a fully coupled forward-backward stochastic system associated with a five-dimensional Hamilton-Jacobi-Bellman equation.