Integrated Modeling Approaches to Quantify Vehicle-to-Grid Services in an Evolving Power Sector

by

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Technical Summary

Electric vehicle charging and other new loads, if not sufficiently managed, are anticipated to add significant strain to the power system. In light of these challenges, vehicle-to-grid (V2G) has been proposed as a form of flexible load and decentralized energy storage. Within a V2G framework, grid-connected electric vehicles provide services to power grids, for example by shifting when they charge or discharging their batteries to the grid when power demand is high. Conceptually, V2G can reduce costs, facilitate renewables growth, and provide storage services to the grid.

While V2G continues to evolve and gain market traction, there remain several aspects of the technology, both operational and economic, that stand to be better understood and improved upon to best facilitate widespread adoption. For instance, EVs can theoretically displace stationary energy storage, but to what extent? What are demand side implications for the grid? For early technology adopters, particularly commercial fleets, how can one accurately simulate V2G and other service outcomes and do the potential revenues justify initial investment? This thesis addresses such questions and concerns through the development and application of methods that (1) quantify the technology's ultimate value proposition at the systems level, and (2) enable risk-informed market participation and financial analysis.

First, capacity expansion modeling is leveraged to assess V2G through the lens of long-run system value at a regional resolution and its implications for future generation and stationary storage capacity requirements. Studying a 2050 New England power system subject to high EV penetration and tight emissions constraints. V2G's effect on system capacity and value is substantial, with participation from 13.9% of the New England light-duty vehicle fleet displacing 14.7 GW of stationary storage (over $700 million in capital savings).

Next, stochastic models and cost analysis frameworks are introduced to simulate V2G market opportunities and technoeconomic analysis from the perspective of individual fleet owners. Results emphasize the shortcomings of deterministic modeling approaches and identify contemporary tariffs as a barrier to unlocking V2G's full benefits. Several V2G participation strategies are simulated and shown to economically surpass incumbent gasoline powertrains within 3 years of purchase.

Finally, ancillary models are introduced to support analysis and planning: a formulation for V2G representation within generic power systems models and a long-haul trucking fleet modeling platform for cost, emissions, and demand-side projections. In conjunction with the fleet-level analysis, these tools serve to inform the alignment of EV fleet and system incentives.

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