A Kia Niro plug-in hybrid electric vehicle and Nissan Leaf all-electric vehicle plugged in at a public charging station. *Photo from Erik Nelsen, ICFx 65894*

Electric Vehicle Managed Charging: Estimating the Potential Bulk Power System Value

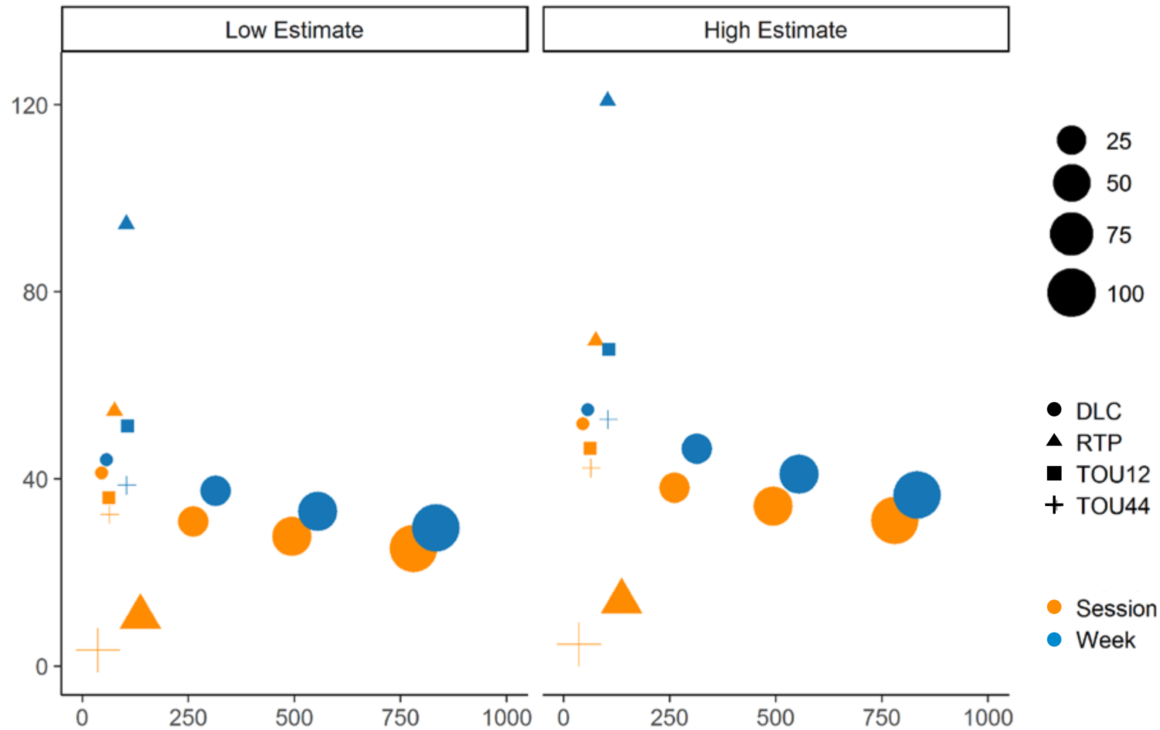
With more and more electric vehicles (EVs) on the road, the grid of the future can greatly benefit from EV managed charging, which coordinates charging based on people's travel needs, electricity supply, and grid conditions. The added flexibility could be especially valuable for the bulk power system as it transitions to high shares of variable renewable generation, like wind and solar.

Numerous studies have estimated the potential value of EV managed charging.[1] In this study, NREL leveraged more detailed modeling of EV adoption, use, charging,[2] and bulk power system operations to understand the potential value. Unique to this study, NREL modeled different charging flexibility types and dispatch mechanisms—as well as participation rates among drivers in having their EV charging managed—starting from vehicle-specific descriptions of charging flexibility.

The study is based on a passenger light-duty vehicle adoption scenario with 100% EV sales by 2035 and a New England power system in 2038 with 84% clean generation and 26% of the electric load met by net imports. The 2038 New England light-duty vehicle fleet is modeled as 45% electric.

[1] Anwar, Muhammad Bashar, Matteo Muratori, Paige Jadun, Elaine Hale, et al. 2022. "Assessing the Value of Electric Vehicle Managed Charging: A Review of Methodologies and Results." Energy & Environmental Science. https://doi.org/10.1039/D1EE02206G.

[2] Yip, Arthur, Christopher Hoehne, Paige Jadun, et al. 2023. Highly Resolved Projections of Passenger Electric Vehicle Charging Loads for the Contiguous United States. Golden, CO: National Renewable Energy Laboratory. https://www.nrel.gov/docs/fy23osti/83916.pdf.



Low and high estimates of total bulk power system cost savings per vehicle per year for 16 combinations of flexibility type, participation rate, and dispatch mechanism. The two estimates differ in the monetary value assigned to avoided carbon emissions and firm capacity.

More Detailed Modeling With Less Computational Cost

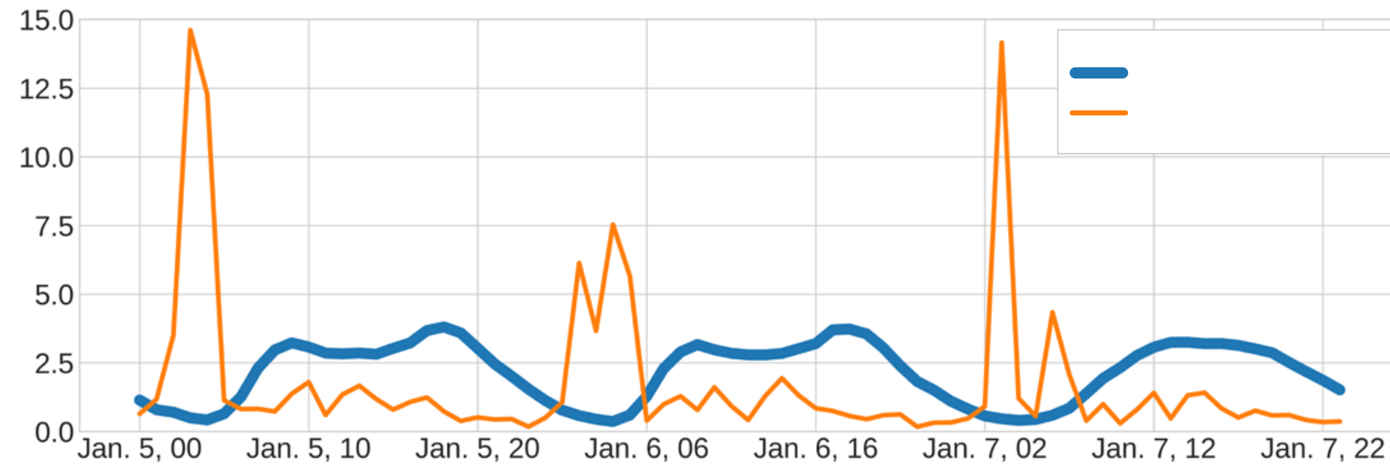
The most accurate way to model charging flexibility is to explicitly constrain each individual EV, but the computational cost of that approach is not feasible for scheduling thousands or millions of EVs alongside grid resources like generators, transmission flows, and storage resources. On the opposite end, the simple aggregation models common in the literature significantly overestimate megawatt-scale flexibility of the EV fleet because they can, for example, unrealistically pair one already-full, but plugged-in, vehicle's ability to increase load with another already-charging vehicle's ability to accept more energy. As a middle ground between the two modeling approaches, NREL ran computational experiments to tune scaling factors that can be applied to existing aggregation techniques to produce more realistic results.

Key Benefits and Limitations of Different Dispatch Mechanisms

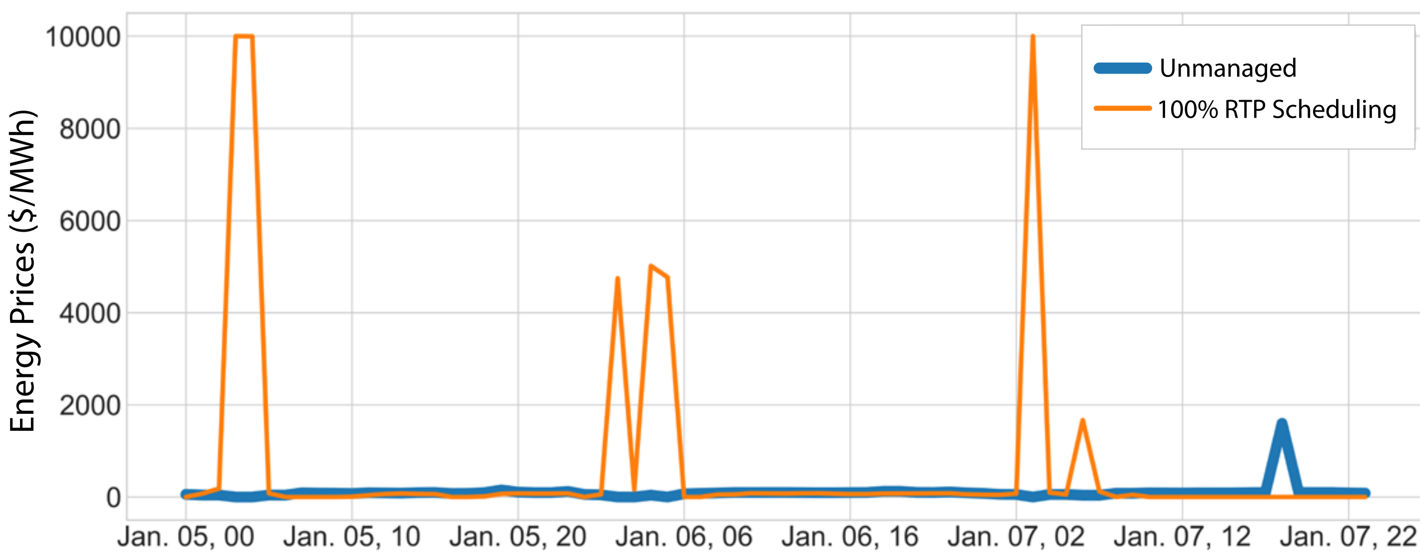
The study methodology enabled NREL to identify the benefits and limitations of three EV managed charging dispatch mechanisms: (1) direct load control in which the grid operator dispatches storage-like, megawatt-scale aggregations of EV charging flexibility alongside supply-side resources to minimize system costs, (2) real-time pricing in which individual vehicle charging is scheduled to minimize charging costs as defined by hourly day-ahead wholesale electricity prices, and (3) time-of-use tariffs, which are similar to real-time price profiles but use coarser multihour, seasonal price signals.

The absolute and relative value of the mechanisms changes with the quantity of participating EVs and the time horizon of EV charging scheduling decisions. Highlights from the study results include:

- At low participation rates, price-taking dispatch mechanisms, especially the hourly real-time price, can provide more value than direct load control.
- Even at low participation levels, price-taking dispatch mechanisms provide more value when paired with some sort of coordination or damping of the response.
- Simple price-taking dispatch breaks down at fairly modest participation rates (less than 15% of the light-



a) EV Charging Profiles



b) Price Profiles

EV managed charging implemented with real-time pricing always reduces or eliminates the price spikes in the day-ahead unit commitment model but can create even larger price spikes at other times because of the dramatic EV load shape changes induced by many vehicles responding to the real-time price in an uncoordinated fashion. This figure depicts the study's most dramatic scenario: all 5.3 million EVs scheduling their weekly charging based on an approximated week-ahead RTP.

duty vehicle fleet) when the EV managed charging response is unanticipated by the day-ahead unit commitment and dispatch schedule. In contrast, direct load control works well over the full range of participation rates.

- Simple scaling of aggregate flexibility parameters can yield megawatt-scale resources for which the requested dispatch is likely to be feasible (with very low error) when disaggregated to charging requests for individual vehicles. However, the simple scaling requires approximately halving the capability of the naive "outer approximation."
- Scaling energy and power bounds less aggressively can yield a megawatt-scale aggregate EV charging resource whose realized dispatch is likely to differ significantly from the initial request but better maximizes the aggregation's expected profitability.
- Depending on the metric, within-week flexibility can be 70%–100% more valuable than within-session charging flexibility at low participation rates, but the effect is muted at higher participation rates, dropping to 15%–25% at moderate (30%) and higher (100%) participation rates.

Fundamental Considerations for Aggregators, Utilities, and Independent System Operators

Some of the challenges with dispatch mechanisms identified by this study can be handled by aggregators, utilities, and independent system operators as they gradually implement and operate EV managed charging programs, but there are a few important phenomena to be aware of:

- Responses to real time price and time-of-use rates may need to be dampened or smoothed in some way, even at low participation rates.
- At low participation rates, allowing vehicles to respond directly to real-time prices could be the simplest and most valuable approach to implementing EV managed charging. However, there is not clear guidance on how to effectively design and operate such a program at high participation rates when large quantities of load simultaneously respond to the same price.
- Even with perfect foresight and control, grid operator schedules for megawatt-scale aggregations of vehicle charging flexibility cannot be exactly fulfilled by individual vehicles. However, forecast errors can be understood, mitigated, and managed through experimentation and experience.
- Megawatt-scale aggregations can be tuned to reduce dispatch errors the grid operator must make up for or to maximize aggregator profit. If insufficient care is taken, the aggregate dispatch requests can be suboptimal for both the grid (high error rates) and aggregator (reduced profit).
- It is possible to dispatch pseudo-storage resources representing EV managed charging alongside utility-scale resources in unit commitment and economic dispatch models. Doing so can be computationally challenging, though, especially for small resources or within-week EV managed charging that requires longer look-ahead times than what is currently used in independent system operator markets.

Learn More

Download the report at https://www.nrel.gov/docs/fy22osti/83404.pdf.

Download the report describing the underlying transportation data set at https://www.nrel.gov/docs/fy23osti/83916.pdf.

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