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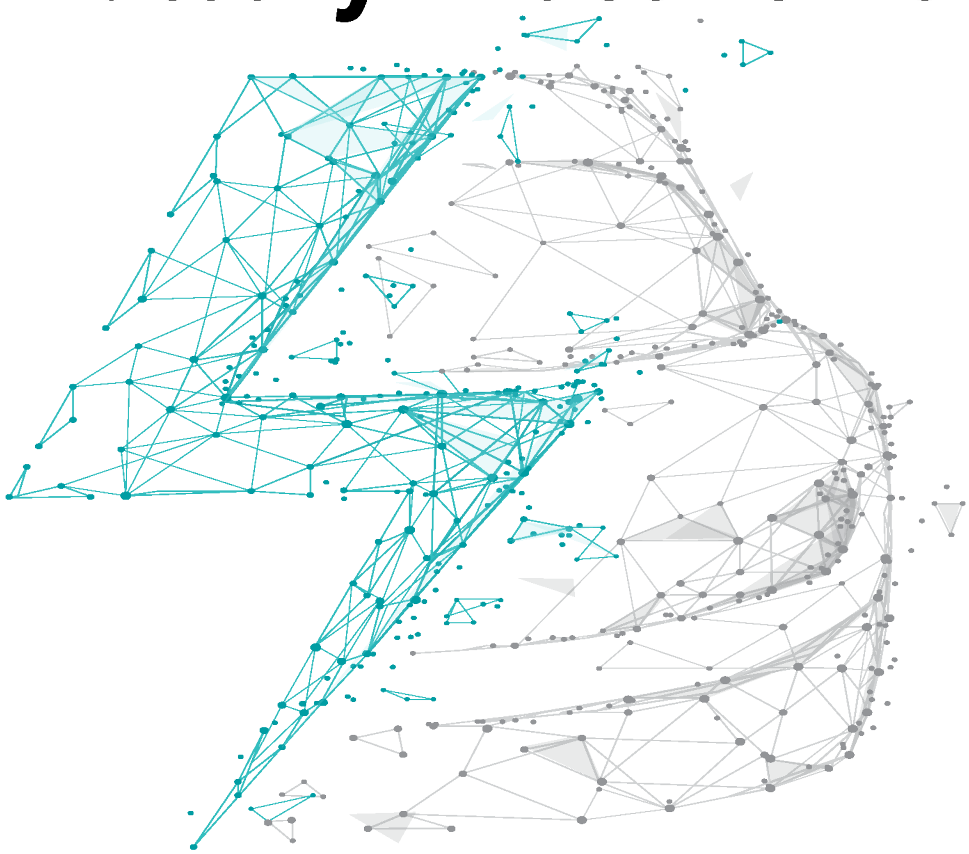
EV WATTS
WHTEPAPER SERIES

Optimizing Battery Size for Fleet Battery Electric Vehicles



EV WATTS
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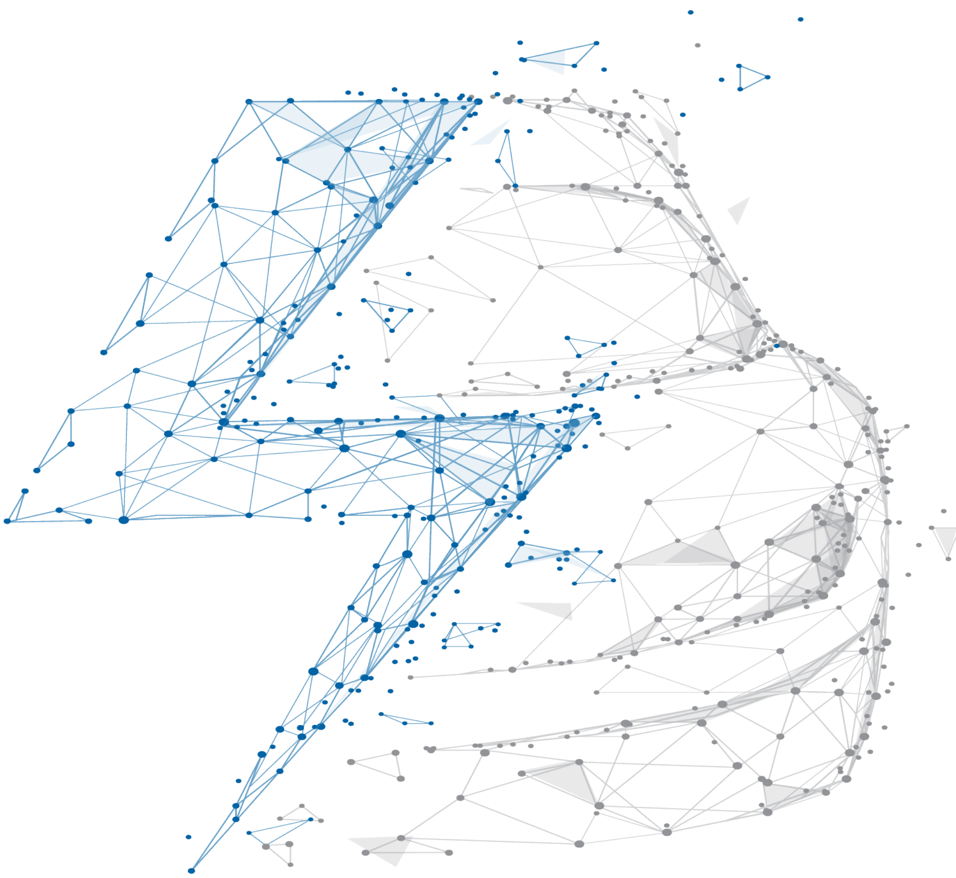

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Optimizing Battery Size for Fleet Battery Electric Vehicles

Energetics leads EV WATTS (Electric Vehicle Widescale Analysis for Tomorrow's Transportation Solutions), a multi-sector project that facilitates the nation's move toward sustainable transportation. The project is collecting real-world use data from plug-in EVs and charging stations to address a growing need for practical information about vehicle electrification. The team analyzes these data to improve our understanding of driving and charging patterns. EV WATTS is helping to demonstrate how the latest advancements in EVs and charging station technology address barriers, improve the business case for electrification, and determine what behavioral changes electrification may require.

The project uses charging station data and vehicle usage data to build one of the largest datasets of its kind. The data collected for EV WATTS is aggregated and anonymized so that it can serve as a resource to researchers, policymakers, and other stakeholders. Using the data, the team has created interactive dashboards that display statistics and findings from EVs and charging stations. The dashboards allow users to explore this anonymized dataset, looking at energy demand, use patterns, charging details, and more. The most recent EV WATTS dashboards are available at EVWATTS.org.

EV WATTS is sponsored by the U.S. Department of Energy (DOE). Input and other assistance is provided by DOE national laboratories, Clean Cities Coalitions, fleets, state and local governments, vehicle manufacturers, utilities, EV drivers, and charging station providers.

Introduction

Optimizing battery size in an electric vehicle (EV) can amplify the benefits of EVs. This study examines all-electric fleet vehicles in the EV WATTS dataset (see sidebar) to analyze battery size, battery use, and charging patterns. We estimate the prevalence of suboptimal-sized batteries and present a method to determine appropriate battery sizing.

Reasons to Optimize Battery Sizes

Organizations across the nation are electrifying their vehicle fleets, motivated by the promise of reduced costs and environmental impacts. Both these factors could be improved by right-sizing vehicle batteries. An improperly sized battery negatively affects the vehicle's cost, efficiency, longevity, and convenience.

Battery sizes affect charging patterns, which, in turn, affect battery longevity. According to the vehicle manufacturer Kia, limiting the amount of time that a battery state of charge (SOC) is higher than 75% and lower than 25% can significantly increase battery lifetime (2022). EV batteries that are larger than necessary often maintain a high SOC (above 75%), which not only decreases battery life but also leads to excessive idle charging (i.e., EVs occupying charging infrastructure unnecessarily). EV batteries smaller than needed often reach a low SOC (below 25%), requiring long or frequent charging and decreasing battery life.

Right-sizing the battery ensures optimal charging patterns that increase battery longevity. Batteries are replaced less frequently, lowering the total cost of EV ownership and decreasing battery waste. This strategy also decreases idle charging, improving vehicle agility and convenience and limiting unnecessary charging en route.

In short, replacing an overly small battery with an optimal (larger) battery reduces:

- Charging frequency
- Battery replacement frequency

Replacing an overly large battery with an optimal (smaller) battery reduces:

- Battery costs (both initial and replacement)
- Tax liabilities
- Battery waste
- Vehicle weight

As defined in this study, an optimal battery size is small enough to keep a vehicle's SOC below 80% between charging events and minimize idle charging, but large enough to allow for full trips without (1) excessive stops for charging or (2) frequent near-depletion of the vehicle battery.

Data

EV WATTS Data

The EV WATTS data used for this study include driving and charging patterns by fleet and vehicle, vehicle ownership, vehicle and fleet counts, vehicle battery sizes, geographical locations, and vehicle SOC. The specified subset of the EV WATTS dataset used in this study contains 489 battery electric vehicles (BEVs) within 39 fleets, each with its own predominant driving pattern. Approximately 93% of the vehicles are sedans; the remainder are buses and SUVs.

Outside Data

The researchers gathered data on vehicle efficiency from the U.S. Department of Energy and U.S. Environmental Protection Agency's shared fuel economy estimates (n.d.). The data were used to calculate the kilowatt-hours (kWh) expended during vehicle trips. The User Miles per Gallon (MPG) was used whenever available, and for instances in which there was no reported user fuel economy, the EPA MPG was used. The MPG was then converted to kilometers (km) per gallon, and further converted to km per kWh, which was used to determine kWh per trip.

Methodology

To determine whether a vehicle's battery is optimal or suboptimal, the team considered the following data attributes: SOC, current battery size, vehicle trip length, and daily kilowatt-hours exerted.

To maximize battery use and longevity, vehicle batteries that consistently remained at a high SOC (above 80%) were deemed too large, and vehicle batteries that consistently reached a low SOC (below 20%) after trips were deemed too small.

Researchers used a preliminary calculation for analysis purposes. Statistics used to determine an optimal battery size were the average energy in kilowatt-hours exerted during vehicle trips (based on the vehicle trip length) and the amount of energy that would permit 90% of trips to occur. An optimal battery size was considered to be at least twice as large as the average energy consumed per day and no larger than a battery that could handle 90% of the daily kilowatt-hours exerted, rounded up to the nearest multiple of 10 (e.g., if this calculation resulted in an energy level of 17 kWh, the maximum optimal battery size would be 20 kWh). This proposed calculation is written as follows:

$$X > 2Z$$

$$X < \lceil Y \rceil_{10}$$

Where X = optimal battery size, Z = mean daily kWh exerted, and Y = 90th percentile of daily kWh exerted, rounded up to the nearest multiple of 10.

The calculated results serve as the defined optimal battery size for vehicles in this analysis.

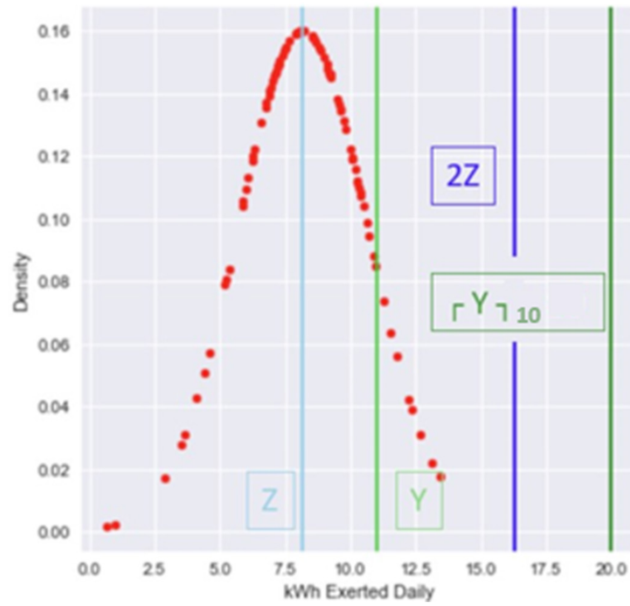

Figure 1 Example daily kilowatt-hour distribution with bound lines

Figure 1 illustrates the crucial data points in a daily kilowatt-hour distribution that structures the upper and lower bounds of the optimal battery, based on these equations.

Findings

In the final analysis, the equations described above proved a strong determiner in identifying optimal battery size. Using this calculation, researchers evaluated the 489 BEVs in the EV WATTS dataset and found that over 97% had batteries that are larger than optimal. Of these vehicles, over 31% have batteries more than twice as large as the proposed upper bound. (One vehicle with an average daily energy expenditure of less than 5 kWh has a battery size of 75 kWh.)

Vehicle A (in **Figure 2**) is provided as an example of a typical BEV in the dataset. The vehicle is equipped with a 40 kWh battery. As **Figure 2** shows, the SOC is continuously high at plug-in, indicating that the battery is unnecessarily large. A smaller battery would shift the average plug-in SOC closer to 50%.

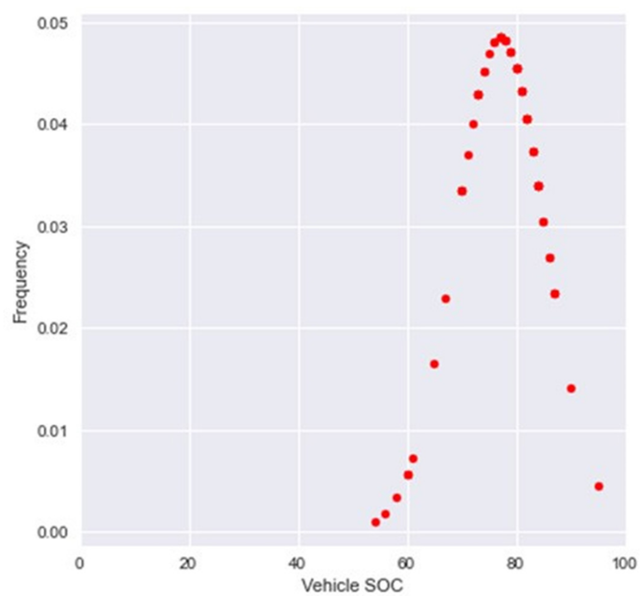

Figure 2 Vehicle A SOC distribution at plug-in

To determine the optimal battery size, researchers looked at Vehicle A's average daily kilowatt-hour expenditure: 8.2 kWh per day and less than 2 kWh per trip. According to the proposed optimality standard, Vehicle A should have a battery size:

- Larger than two times the mean daily kilowatt-hours (8.2 kWh), or 16.4 kWh
- Smaller than the 90th percentile of daily kilowatt-hour use (10.9 kWh) rounded up to the nearest multiple of 10, or 20 kWh

In short, an optimal battery size for Vehicle A is between 16.4 and 20 kWh. BEV options on the market around this range include vehicles with 17.6 kWh and 23 kWh battery packs (Electric Vehicle Database 2023).

Figure 3 shows Vehicle A's daily energy expenditures in comparison with three battery sizes: 16.4 kWh, the lower bound for an optimal battery size (blue line); 20 kWh, the upper bound for an optimal battery size (green line); and 40 kWh, Vehicle A's current battery size (red line). The red dots show the distribution of kilowatt-hours exerted on each day that Vehicle A was active. If a red dot sits to the left of a vertical line (or battery size), that energy expenditure (or trip) would be possible with that specific battery size. Figure 3 illustrates that the optimal battery size (16.4–20.0 kWh) would allow Vehicle A to maintain current operations, with all the benefits associated with downsizing an overly large battery.

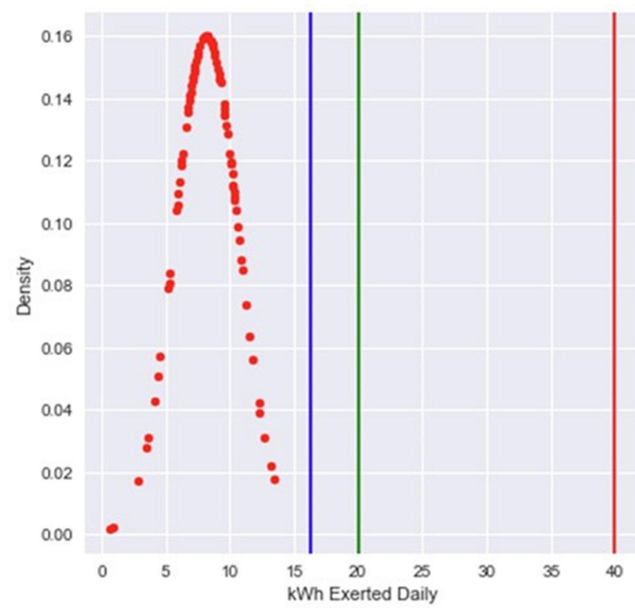

Figure 3 16.4 kWh (blue – smallest size of optimal range), 20.0 kWh (green – largest size of optimal range), and 40.0 kWh (red – current vehicle battery size)

Conclusions and Considerations

Using data from the EV WATTS dataset, the following preliminary efficiency bounds were developed:

$$X > 2Z$$

$$X < \lceil Y \rceil_{10}$$

Where X = optimal battery size, Z = mean daily kWh exerted, and Y = 90th percentile of daily kWh exerted, rounded up to the nearest 10.

Based on these equations and EV WATTS data, a significant percentage of fleet BEVs have batteries that are larger than optimal, leading to unnecessarily high battery costs, additional vehicle weight, and shortened battery lifespans.

Of course, “optimal” will vary with specific fleet needs. A fleet may want to ensure a vehicle can travel longer, or provide multiple days of service, between charging events. That fleet would procure BEVs with batteries that are larger than optimal (as defined in this study). This study’s proposed optimization is based on past data; fleets may adjust the upper bounds (for example, from the 90th to the 95th percentile) to accommodate their operations.

Similarly, vehicles with low usage may make adjustments to the optimization approach. The calculations can be based on energy expended per individual trip, rather than daily energy consumption. The daily consumption approach assumes that the vehicle charges only after all trips for the day have been completed. The energy-per-individual-trip approach assumes that the vehicle charges between trips.

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